An Evaluation of the UK Skills Base for Toxicologists and Ecotoxicologists, with Focus on Current and Future Requirements, Particularly with Regard to the Skills Required for the Hazard Assessment of Chemical Substances including Nanomaterials.

Prepared For: DEFRA, UK.

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Contract Number: RR102321

26th June 2009

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FINAL REPORT

26th June 2009

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Executive Summary

There are concerns about the skills base and capacity of the scientific community to evaluate chemical substances. In particular the availability of suitably experienced toxicologists, ecotoxicologists, and chemists to meet the requirements of new legislation such as REACH, and from nanotechnology. The overall aim of this report was to determine the UK skills base in toxicology and ecotoxicology to support the hazard evaluation of chemical substances, now and in the future. Consideration was also given to the number of chemists, physical scientists, and other supporting life sciences. The approach included: (i) a literature review of the apparent concerns, (ii) a survey of scientists from government, academia, industry and consultancy, (iii) a smaller survey of A-level students and undergraduates, and (iv) a workshop and interviews of scientists. A total of 358 responses were obtained from the scientific community and 90 respondents to the student survey. The main findings identify a loyal workforce with experience of many different types of chemicals, including nanomaterials. Only a fraction of the workforce is conducting practical work at the bench and respondents to the survey identified a number of priority skills gaps include risk assessment skills, practical knowledge of regulation and policy, practical statistics, specific specialist bench skills, generic report writing skills, and practical aspects relating to *in vivo* experience with animals. Current scientists already have high workloads in all sectors of employment; with skills missing from their teams. There are not enough scientists to meet the predicted future workloads. The skills shortage is partly caused by an inability to recruit new staff, and a lack of suitable applicants with the necessary skills was an issue for all sectors of employment. Effort needs to be invested in the training of scientists, and this is a shared responsibility across all sectors of employment. Students are not choosing specialist undergraduate degrees in the discipline. The consensus view was that specialist training in the toxicological sciences should occur at post-graduate level. More practical training is required and steps should be taken to retain experienced post-doctoral scientists in the profession. A number of recommendations are made on solving these problems, and the importance of a multi-disciplinary implementation strategy is identified.

Preface: Background to the report

This report was commissioned by DEFRA, but with interest from a number of other government departments. The scientific community has had anecdotal concerns about the training of scientists and the sustainability of the skills base in science for some years. In some areas of science, such as biomedicine, these concerns are being addressed. However, there remains a paucity of firm evidence (data) in the general area of hazard evaluation of substances and chemical safety to support anecdotal opinion about the skills of scientists, and the workforce capacity, in this arena. Some data and opinion from the chemicals community needed to be collected. In addition, at this time, industry is faced with a variety of new chemicals legislation and other safety legislation. Regulators are also currently in the process of trying to agree international standards, regulatory systems and risk assessment protocols for new substances such as nanomaterials. One concern is that a potential skills shortage, or lack of particular skills, has arisen at a time when there is much work to be done in the immediate future as a result of new legislation and other drivers. The overall aim of this report was to determine the UK skills base in toxicology and ecotoxicology to support the hazard evaluation of chemical substances, now and in the future. Since such evaluations cannot be performed by (eco)toxicologists in isolation consideration was also given to the number of chemists, and other physical scientists, as well as supporting areas in the life sciences. One example of new substances, where the technology has the potential to produce a myriad of chemical forms in the future, is nanotechnology. So, an additional overarching aim was to include the nanoscience community in this evaluation of skills and future needs. Our specific objectives included:

(i) Preparing a literature review on the various forecasts for the amount of work under new and current legislation, especially REACH in the context of the skills requirement.

(ii) Surveying scientists, including those working on nanomaterials, for their views on how they are working now, the skills gaps and issues they report, and suggestions on how these might change in the future.

(iii) Analyse the responses of the scientific community and make recommendations on the way forward.

Our approach has been broad in an attempt to obtain the views of scientists from government, academia, industry and consultancy. We deliberately targeted the survey at individuals (not corporate responses) so that we obtain the reality and personal views from people working on the ground in this area of science. In addition, we recognise that some of the skills issues may have their roots in the education system, or the way young people view our science and their career prospects in science. So as an additional task, we also sought the views of a group of A-level students, and undergraduates, to find out why they were apparently not choosing a career path in the toxicology, chemistry, and related interdisciplinary topics within the environmental sciences.

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1.0 An evaluation of the UK skills base for toxicology and ecotoxicology: A brief literature review

There is a growing perception that there will be an inadequate pool of trained scientists, with the right practical skills and theoretical knowledge, to meet future needs in the UK and the EU. The area of hazard and risk assessment is of particular concern because of the statutory obligations to ensure the safety of chemicals and pharmaceuticals, under existing and new legislation. The aim of this mini-review is to outline the current evidence for these concerns, and highlight the knowledge gaps on this topic.

1.1 Higher education

The perception amongst lecturers at Higher Education Institutes (HEI's, universities, colleges) is that the quantity of practical work in undergraduate science degrees has been gradually eroded over the last 20 years, but despite this possibility, there are numerous reports of practical teaching methods in the literature (e.g., A-Brook and Weyers, 1995; Mozdziak et al., 2004; Jez et al., 2007; Kroll, 2007; Pham et al., 2008). The reasons for the perceived reduction in practical work may be complex, and in the life sciences may include less use of animals for practical work, resource constraints on staff, and restricted supply of suitably experienced academics (see below). Nonetheless, this perceived reduction in practical work is evident in many areas of science including biology, chemistry and other disciplines in the physical sciences. Consequently, we may now be producing graduates with less 'hands on' skills at the bench compared to 10 or 20 years ago. The evidence for this perception of a practical skills shortage comes from a variety of sources. Firstly, the market for most post-graduate masters level programmes that include a strong practical element is growing, and is partly an attempt to top up graduate skills to enable employment. However, it is also creating a situation where post graduates are not obtaining work in the field of their choice with 24 % of masters taking employment in a job for which they are "over educated" (Dolton and Vignoles, 2000). There have also been opinions voiced by professional bodies with responsibility for vocational or accredited undergraduate degrees; in biomedical sciences for example there is a clear message that more practical training is needed (ABPI, 2008). Practical training also remains a strong element for inclusion in the Register of Toxicologists (Fowler and Galli, 2007).

The cause of this apparent shortfall in undergraduate practical training is multifaceted. Academics are under increasing pressure from research assessment exercises (the last RAE, and the similar exercises planned for the future), teaching quality audits (e.g., Quality Assurance Agency for Higher Education, QAA), and the large increase in the number of students in higher education over the last decade. The number of full time undergraduate students studying pharmacology, toxicology, or a pharmacy subject was 13715 in 2007/08 (Higher Education Statistics Agency, http://www.hesa.ac.uk/index.php?option=com_datatables&Itemid=121&task=show_category&catdex=3#subject), compared with 7939 in 1997/98. These statistics group pharmacology and toxicology subjects together, so it is not possible to extract data just for toxicologists. Available admissions data shows a slow steady increase in annual applications and places available for subjects that come under the pharmacology, toxicology and pharmacy umbrella. In 2008, the number of undergraduate applications was 24,621 which resulted in 4,122 acceptances; a ratio of 6:1. The numbers for 2003 were 18,919 and 3,153, respectively, showing a 25 % increase over the last six years (Universities and Colleges Admissions Service (UCAS), http://www.ucas.ac.uk/about_us/stat_services/stats_online/data_tables/appsaccpssubs/). However, despite this increase at current levels toxicology and pharmacology students together account for only about 0.5 % of the total student population. An important point to note is that many of the courses are vocational and a high proportion of these students go into the health sector upon graduation (81.9 %), and of these 77.9 % become pharmacists, and 3 % pharmacologists. In comparison, well over half of biology graduates take up work placements that are unrelated to the subject, with just 12.8 % choosing scientific research (Data for 2007 graduates, Graduate Prospects Limited http://www.prospects.ac.uk/cms/ShowPage/Home_page/What_do_graduates_do_/charts_and_tables_page/p!eefffpL?subject_id=34).

In addition, the financial value of each student has dropped in real terms, as estates costs and other overheads have increased. Thus, HEI’s are faced with training more students, inevitably with some less motivated students in the large pools of applicants, with less money per student and with increasing demands on staff time. Consequently, the most time consuming and expensive elements of student training have been in decline (i.e., the practical work). Another factor has been an explosion of new theory-based or theoretical topics over the last two decades including molecular biology, genomics, metabolomics, computational biology or bioinformatics, and biotechnology. The question therefore arises as to whether it remains viable to teach all these theory topics as well as practical skills in a 3 year degree programme. Furthermore, for toxicologists and ecotoxicologists, some significant training in chemistry is essential, yet chemistry departments are closing in the UK. Twenty-six universities ceased to offer chemistry degrees during the period 1996 – 2006 (POST, 2007). The highly prestigious chemistry department at Sussex University (it housed three Nobel laureates) was saved from closure after a concerted campaign. Sussex chemistry was the first 5 research rated department to be threatened with closure. Until Kings College London, which closed in 2003, all closures had been of departments with 3 ratings or lower. Such a high profile case highlighted the need for more government funding for laboratory-based subjects (RSC Bulletin http://www.rsc.org/ScienceAndTechnology/Policy/Bulletins/Issue4/SavingofSussex.asp). Clearly, aspects of the multidisciplinary provision needed for the training of toxicologists may be restricted by the availability of a local chemistry department.

There are of course innovative uses of technology and teaching methods to improve the efficiency of education. For example, case-study approaches to develop critical thinking and analytical skills (Mayo, 2002), as well as the use of the internet and other information technology (Schaverien, 2003). However, there is no substitute for practical experience (e.g., Johnston and McAllister, 2008; Hope, 2009) and in the end time and effort must be devoted to practical training.

1.2 PhD and post-doctoral training

The number of full-time post-graduate students in pharmacology/toxicology has doubled in the last decade, from 1067 in 1997/98 to 2775 in 2007/08

(HESA statistics). However, the number of new substances that require safety evaluation has risen, to current estimates of around 30,000 chemicals (Ackerman and Massey, 2004). It is therefore clear that there is a discrepancy between the number of scientists and the burden of testing. In addition, the reasons why PhD students are not being retained as post-doctoral scientists are unclear, but the relative financial return in salary for those staying on in post-graduate study is less than those who leave at undergraduate level and go into work (Dolton and Vignoles, 2000). There is a perception amongst academics that post-doctoral workers leave bench science, or leave science completely, after completing only one post-doctoral position. The short term contract market is blamed for this exodus (Oliver and Ackers, 2005). In addition, over the last decade many toxicology laboratories have moved their operations to developing countries (for cost effectiveness reasons) and inevitably the availability of positions based within the UK will have declined. Clearly, the retention of post-doctoral scientists is important, but with only 2775 full time postgraduate students in pharmacology/toxicology in the UK in 2007/08 (HESA, link above), it is inevitable that the number of post-doctoral scientists will be less than that.

1.3 Maintaining the supply of key specialist staff

There are some areas where a shortage of critical staff can prevent the entire process of data collection for hazard assessment. These represent “bottlenecks” in our human resource, and thus limit the capacity to conduct testing. For example, the absence of a qualified veterinary surgeon, or the named animal care and welfare officer (NACWO), to make daily/routine independent checks on animals during acute toxicity tests would mean that the tests cannot be conducted. The general shortage of veterinary surgeons with experience of large and small animals is known (840 vets graduated in 2007, HESA statistics), but what is unclear is why veterinary surgeons do not choose to get more involved with monitoring animal welfare in regulatory settings, or as an independent veterinary surgeon under the Home Office Scientific Procedures Act 1986.

Similarly, for clinical trials, each phase 1 safety trail has an absolute requirement for a qualified doctor to be present (i.e., immediately available to deal with a medical emergency). The evidence for ease or difficulty in recruiting doctors to the testing of pharmaceuticals is unclear, but there is a perception that doctors complete this role on a "locum" basis, rather than as a career path or other more permanent employment.

In ecotoxicology, the animal welfare issues are less critical because many tests are conducted on invertebrate species or plants (aquatic and terrestrial) for regulatory requirements. However, regulatory acute or chronic (including life cycle) toxicity tests in fish require similar home office ethical approvals, and the study director must be competent in recognising suffering, distress or lasting harm in the animals. The approved animal welfare training is widely available at a modest cost (modules 1-5 to obtain both personal and project licences from the Home Office), and this should not be an impediment to contract research organisations (CRO's) ensuring the supply of staff. Similar arguments apply to mammalian toxicity testing in the regulatory arena. However, there are some critical bottlenecks in fundamental research. The number of scientists with skills in surgical techniques on animals appears to be in decline. These techniques include maintenance of catheters, *in situ* perfusion methods, as well as complex anaesthesia with recovery after surgery. These skills have been traditionally taught in academia by whole animal physiologists. In recognition of this and the decline in whole animal biology, the research councils have put in place a few schemes to promote the traditional skills of the animal sciences (e.g., BBSRC, http://www.bbsrc.ac.uk/business/collaborative_research/industry_clubs/mammalian_biology.html). However, the fact remains that many of the original experts in these techniques have already retired and the entire community is reliant on fewer individuals with detailed knowledge of these techniques in the UK. For example, only one laboratory retains continuous use and expertise in fish gill and gut perfusions (Campbell et al., 1999; Handy et al., 2000).

The cause of these problems for whole animal biology was partly the revolution in molecular biology techniques, with many life scientists perceiving the acquisition of expertise in these new techniques as a good way to obtain career progression. Clearly, as in any profession, biology is subject to periods where one topic or set of techniques is more popular than others; but it is important to not let such trends undermine our basic ability to conduct safety testing. There may also be some advantages of the progress in molecular biology for animal welfare, in that molecular and *in vitro* techniques such as animal cell culture may replace some aspects of animal testing within a tiered approach to hazard assessment. However, it is the very same whole animal biologists who originally developed cell culture methods (e.g., Wood et al., 2002 for fish cells), and the training issue remains in these techniques as well.

Other practical tasks, such as chemical analysis, data entry, or statistical analysis can be less sensitive to human resource issues in that samples can be stored until the analysis can be done. While this may delay the overall process of hazard assessment, it does not stop it or prevent it. One possible exception to this is the absence of specialist chemical analysis expertise to verify test materials and stock solutions before experiments are started. One view is that any industrial development of a new material will inevitably also involve the simultaneous development of the physico-chemistry expertise. However, this is clearly not the case for engineered nanomaterials, where there has been capacity building for research (e.g., NERC Environmental Nanoscience Initiative (ENI) grants listed in Defra, 2007a), but also a realisation that expertise in nanochemistry is in short supply. One solution is to develop centres where specialist analysis can be conducted, and for example, the National Physical Laboratory is one such centre of expertise for nanoscience. However, there is reluctance by industry to rely on third parties for practical skills that affect their core business, and new formulations of novel materials may have a high commercial sensitivity or financial value. Clearly, with these commercial concerns it would be preferable for companies to be able to employ their own experts, and here the burden falls on academia to ensure a long term supply of highly skilled post-doctoral chemists.

1.4 Legislation and government policy

The following is a brief summary of the most relevant government policies requiring the need for toxicologist and ecotoxicologists. The European Union informs the majority of the statutes relating to chemicals and the recently enacted REACH[1] legislation which came into force on 1st June 2007, is possibly the most influential with respect to the immediate requirement for toxicologists and ecotoxicologists. Most chemicals are subject to stringent government testing requirements for the evaluation of human health and ecotoxicological safety before they can be marketed. REACH replaced a number of European directives and regulations with a single system. Fleischer (2007) conducted a survey of the cost and capacity for testing under REACH within the EU and concluded that a bottleneck is likely to occur. The best information on the size of the (eco)-toxicity testing market is available for REACH, but even in this sector the data are hotly contested, with estimates ranging from 2 billion to 13 billion Euros over the approximately ten year period of REACH implementation.

Ackerman and Massey (2004) arguably performed the most comprehensive analysis of costs before REACH was implemented. Table 1 shows their estimate of the number of Registrations expected per tonnage band and the consequent estimated testing costs. We have assumed that the split in costs between environmental and mammalian toxicology tests is approximately 30:70. These estimates suggest that about 57 % of the environmental testing required under REACH will take place, or will be contained in plans submitted to ECHA, within the next two years, with another 33 % of tests taking place before 2013. Only 10 % of the overall number of tests will be required to support registrations after 2013. However, although the timetable is challenging, advice from the European Chemicals Agency, ECHA (Sharon Munn, Pers. comm.), is that they will take up to the following amounts of time to consider testing plans submitted with registrations:

- 2010 deadline (for substances manufactured/imported at >1000 tonnes per company): up to two years to consider testing plans, so testing may start in 2012.
- 2013 deadline (for substances manufactured/imported at 100-1000 tonnes per company): up to three years to consider testing plans, so testing may start in 2016.

[1] Registration, Evaluation, Authorisation and restriction of CHemicals

- 2018 deadline (for substances manufactured/imported at 10-100 tonnes per company): up to four years to consider testing plans, so testing may start in 2018 (after substance information exchange forums, SIEFs, have been disbanded).

Table 1. The number of registrations expected for REACH.

	Volume Band (tonnes/year)			
	>1000 (deadline 2010)	*100-1000 (deadline 2013)*	*10-100 (deadline 2018)*	*1-10 (deadline 2018)*
Substances: phase-in full registration	3685	2953	5846	18696
Substances: phase-in "less onerous"	653	61	0	0
On site intermediates	2600	3500	14000	8500
Transported intermediates	1700	1500	2300	5000
Downstream unintended uses	3021	3302	1661	1520
Estimated costs of testing (all tests) – millions of Euros	1712	978	203	110
Estimated costs of testing (environmental only) – millions of Euros	514	293	61	33

Whilst one of the aims of REACH is to promote the use of alternative methods for the assessment of the hazardous properties of substances, many of the methods available have yet to be fully validated. Pedersen et al. (2003) carried an assessment of additional testing needs under REACH. The estimated testing needs are shown in Table 2. This is based on a total of 29,342 substances requiring registration and two scenarios. The minimum test needs scenario appears when either waiving of specific tests or extensive use of (Quantitative) Structure Activity Relationships, (Q)SARs, grouping and read-across techniques is employed. In the maximum test needs scenario it is assumed that the developmental toxicity study and/or the two-generation reproductive toxicity study need to be conducted for 25 % of the substances for which no data are available. Furthermore, only limited use of (Q)SARs, grouping and read-across techniques is assumed.

A large number of these tests require testing on invertebrate animals, namely the *in vivo* mutagenicity study, the development toxicity study and the two-generation reproduction study.

Table 2. Estimated testing needs (% of total number of substances).

Test	Minimum	Average	Maximum
Skin sensitisation	7486 (25.5)	10293 (35.1)	13728 (46.8)
Eye irritation (incl. *in vivo*)	5923 (20.1)	6910 (23.5)	8182 (27.9)
In vivo mutagenicity study	6580 (22.4)	6580 (22.4)	6580 (22.4)
Growth inhibition algae	2638 (9.0)	5277 (18.0)	11466 (39.1)
Active sludge respiration	4616 (15.7)	4616 (15.7)	4616 (15.7)
Short-term *Daphnia* study	2321 (7.9)	4096 (14.0)	8798 (30.0)
Skin irritation/corrosion (incl. *in vivo*)	1974 (6.7)	3949 (13.4)	5817 (19.9)
Gene mutation study in bacteria	875 (3.0)	2916 (9.9)	6424 (21.9)
Cytogenicity study in mammalian cells	875 (3.0)	2916 (9.9)	6424 (21.9)
Development toxicity study	2408 (8.2)	2893 (9.9)	3711 (12.6)
Two-generation reproduction toxicity	1665 (5.7)	2135 (7.3)	2699 (9.2)

Derived from Pedersen et al. (2003).

The fact that completion of the registration and testing of all chemical substances on the market under REACH has been scheduled to take place over an 11-year period testifies to the vast undertaking it represents. REACH applies to substances manufactured or imported into the EU in quantities of 1 tonne per year or more. Human and veterinary medicines, food and foodstuff additives, and plant protection products (pesticides) and biocides are covered by more specific legislation and have tailored provisions under REACH; the requirement for stringent testing being covered by relevant EU Directives.

The Water Framework Directive (WFD) is one of the most important pieces of European environmental legislation in recent years, requiring all inland and coastal waters to achieve ‘‘good status’’ by 2015. It will do this by establishing a river basin district structure within which demanding environmental objectives will be set, including ecological targets for surface waters and the use of environmental quality standards (EQS) for individual chemical pollutants. Investigation of the substances proposed for inclusion by the European Parliament shows that acute or chronic ecotoxicity data are currently unavailable for some or all of the trophic levels required by proposed EQS derivation methodology. It is also likely that during regular reviews mandated by the WFD, further substances with few or no ecotoxicity data will be prioritized by the EC for derivation of EQS. Crane et al. (2008a) considered what options were available for filling these data gaps without generation of ecotoxicity test data. The use of (Q)SARs, and Quantitative Structure-Property Relationships (QSPRs), Activity-Activity Relationships (AARs), Quantitative Structure Activity-Activity Relationships, or read-across from similar substances was reviewed. Whilst the above methods showed potential to meet the required data gaps, some of the modeling requires further validation. For some substances it is likely that read across will not be suitable, indicating that direct toxicity testing cannot be avoided.

Soil is another resource requiring protection from excessive pollution and where knowledge of toxicology and ecotoxicology is required. In September 2006 the “Thematic Strategy for Soil Protection” was published (EC, 2006a). The strategy identifies contamination as a key threat to the sustainable use of soils. Also, in September 2006 the EU presented a proposal for a directive “Establishing a Framework for the Protection of Soil” (EC, 2006b). However, in December 2007, the Council rejected the Commission's proposal for a Soil Framework Directive. The failure to adopt the directive was largely due to concerns about subsidiarity, with some member states maintaining that soil was not a matter to be negotiated at the European level[2]. In the meantime research is ongoing under the Soil Strategy for England (Defra, 2007b).

The Food Standards Agency (FSA) is an independent Government agency set up in 2000 to protect the public’s health and consumer interests in

[2] http://eusoils.jrc.ec.europa.eu/library/jrc_soil/policy/ .

relation to food, Food safety encompasses amongst other things microbiological, chemical and radiological risks. Policies and advice are based on the best available science. Where possible, science is obtained through published peer-reviewed literature or by consulting scientific experts, including the independent advisory committees attached to the FSA. The FSA also commissions extensive scientific research and survey work where scientific evidence is unavailable (FSA, 2006). As part of the FSA's science strategy for 2005 to 2010, requirements for scientific evidence included better understanding of the mechanisms of toxicity of certain food chemicals, better information and methodology to decrease uncertainty in risk assessments, and more toxicological information to establish intake standards for a wider range of materials. Other areas requiring a continuing pool of scientific expertise encompassing toxicology and ecotoxicology are air quality, drinking water standards and the recreational use of water.

It is also important to maintain a large body of independent scientific experts. Independence is regarded as a prerequisite for scientific credibility to such an extent that the mere perception that independence has been lost or compromised leads to a loss in credibility. It can be difficult to avoid such perceptions arising, which is why it is imperative to maintain an independent body of scientific experts who are (for example) not government employees, industrial scientists with a vested interest in the company products, or academics funded by one particular source that may give rise to the perception of a loss of academic independence. In addition, science cannot be credible and independent if it is overtly politicized without apparent justification of policy. Policy decisions on chemicals and related aspects of safety do need to be made to address public concerns and maintain confidence. The science-base should be able to provide transparent evidence to either support or refute a policy decision. This is of course, a reiterative process where the scientific evidence may be used to help formulate a policy, as well as provide independent evidence of the success (or failure) of a policy that has been implemented. Nonetheless, it also remains essential to have a "blue skies" science-base that is not connected to specific policies on substances, or trends in the scientific community. This at least gives the possibility of some capacity to respond to unknown and completely unforeseen problems in the future. In any event, at the level of the individual there should be a clear delineation between the roles of scientist collecting impartial and transparent evidence, and the roles of others in implementation and policy. Science should be used to inform decision making as part of a holistic approach. Policy makers need to be free to take account of socio-economic considerations as well as scientific factors.

1.5 Conclusions and knowledge gaps in the literature

Clearly, there is a concern about the level of academic “at the bench” training in practical work in science, and about the number of potential scientists taking up undergraduate/postgraduate training in toxicology and related fields. In addition, retention of trained scientists is an issue along with the generation of job opportunities to sustain the pool of scientists. In particular, it needs to be established why scientists move away from the biology and chemistry disciplines that are important to chemicals regulation, and how quickly they move away from working at the bench. Such issues will be addressed in a survey of scientists, which also includes collecting data on the expertise of individuals with different types of chemicals, and expertise of different practical techniques.

2.0 Survey of scientists

2.1 Survey method

An anonymous online survey of scientists was conducted between February and May 2009. The survey was designed to capture opinions from scientists in government, academia, and industry. Opinion was sought from the core disciplines of toxicology, ecotoxicology, environmental chemistry, and risk assessment. However, individuals in supporting disciplines such as biomedical sciences, veterinary science, and other sciences were also invited to take part. Physical sciences and engineering were also included for nanotechnology aspects. The types of cohorts invited to complete the survey are shown in Appendix 1. The survey of scientists is attached as a separate pdf file to this report. In addition to the contracted task, a similar survey focusing on A-level and undergraduate students was conducted (pdf attached to the report). The main aim of the latter survey was to find out why students are not choosing toxicology related topics in higher education, as well as identifying the career intentions of those that do. Survey results were analysed using statistics software (SPSS version 16.0) for descriptive statistics (e.g., proportions of responses to each question) and analysed for co-variate effects to eliminate sample bias in the responses; for example, whether or not the age of the respondent affected the response to particular questions.

2.2 Results of the survey of scientists

2.2.1 Demographics of respondents

A total of 358 responses were obtained from the scientific community. It is not possible to calculate this as a percentage of those invited because the survey was open access on the internet, but the types of groups invited are indicated in Appendix 1. The hit rate on the website was recorded, and between February and May 2009 there were 670 hits; suggesting that 53 % of those going onto the website completed the survey. The respondents were 61 % male and 37 % female. There were no overall statistical differences between the age distribution of males and females in the survey. The tendency for more respondents to be male than female was mirrored across all sectors in the survey (number of males: females in each sector); government 50:26; academia 49:37; industry 74:48; consultancy 46:19. There was a broad age range of the respondents (22-74 years). There was no correlation between age and the main area of expertise given by the respondents (correlation coefficients -0.1). There was a strong ethnicity bias towards whites (88 % of respondents) and only a few Asian (2 %), black (2 %) or Chinese (< 1 %) respondents. The main nationality of respondents was British (85 %) followed by other Europeans (8 %) and North Americans (2 %) with 1 % or less of other nationalities. Most respondents considered themselves as long term residents in the UK (59 %) and only 2.3 % were on a short term research visit to the UK. However, 32 % were uncertain about how long they would be staying in the UK, indicating a potentially mobile workforce. Respondents were living throughout the UK, and as expected this reflected population density with most respondents living in the South East of England (21 %), North West (13 %), South West (13 %), Eastern England (11 %), Scotland (4

%), Wales (3 %), and Northern Ireland (0.8 %). The salary ranges of respondents generally reflected the age distribution with salaries ranging from £10,000 to > £60,000, with a few (0.6 %) retired on low incomes (£5000 or less). Notably, 17 % of all respondents were earning more than £60,000.

2.2.2 Profession and expertise of the respondents

All the respondents had some higher education qualifications, with the minimum of A-levels or equivalent. However, most had a degree or equivalent (38 %), with an additional 38 % also having masters level qualifications. More than half of the respondents held a PhD (211 respondents, 59 %). The topics of their most recent degree qualifications were extremely varied. However, 21 % had their most recent qualification in an area of toxicology, 8 % on ecotoxicology, and 9 % in an area of environmental science. Other qualifications were mainly in specialist areas of biomedical sciences, chemistry or engineering. Notably traditional topics like zoology were equally as strong as molecular biology. Only 28 of the respondents were currently registered for a higher degree, and a majority of respondents were not (254 respondents), suggesting that most had completed their formal educational training.

The respondents considered themselves to be mostly life scientists (including toxicology), environmental scientists, or chemists (Table 3). Only 77 respondents (22 %) were on the UK Register of Toxicologists. Only six medical doctors responded to the survey, and three of these worked as consultant toxicologists (whether on the register or not), and three had other roles in the professions. None considered themselves as a full time toxicologist working on clinical trials. Only one of the veterinary respondents did work that was directly related to regulatory toxicology, with two doing some consultancy, and two doing other work. None of the veterinary surgeons considered themselves to work regularly in areas involving the Animals Scientific Procedures Act (1986).

A cross tabulation analysis was performed to determine whether the professional training of the respondents varied across the sectors of academia, industry, government and consultancy. The proportions of the professions were generally unaffected by sector, although there were more life scientists in industry compared to academia, government or consultancy (98, 45, 35 and 39 individuals respectively). There was also a tendency for more environmental scientists to work in government and academia (20 in each of these categories) compared to industry (10) or consultancy (10). For the scientists who considered their main profession as a regulator, 6 worked in government, 4 in consultancy, 1 in industry, and none in academia.

Table 3. Professional training and background of the survey respondents.

Professional Training	Number of respondents	Percent of all respondents (%)	Number of male:female respondents in each category
Medical doctor	6	1.7	6:0
Veterinary surgeon	4	1.1	3:1
Life scientist (including Toxicologist)	218	60.7	122:90
Chemist	37	10.3	25:12
Physicist	1	0.3	1:0
Environmental scientist	61	17.0	41:20
Engineer	2	0.6	1:0
Social scientist (including science policy)	0	0	-
Regulator	11	3.1	9:1
Health and safety adviser	0	0.0	-
Other	18	5.0	11:7
TOTAL	358	100 %	219:132

The life scientists, including toxicologists, considered themselves expert in a range of areas with the biggest proportion being in mammalian toxicology (Table 4). However, there was a sector bias with most of the mammalian toxicologists being employed by industry (66 respondents), then consultancy (28), government (25) and academia (12). For ecotoxicology, a different sector bias was evident with most ecotoxicologists working in academia (13), then government (5), consultancy (3), and industry (1).

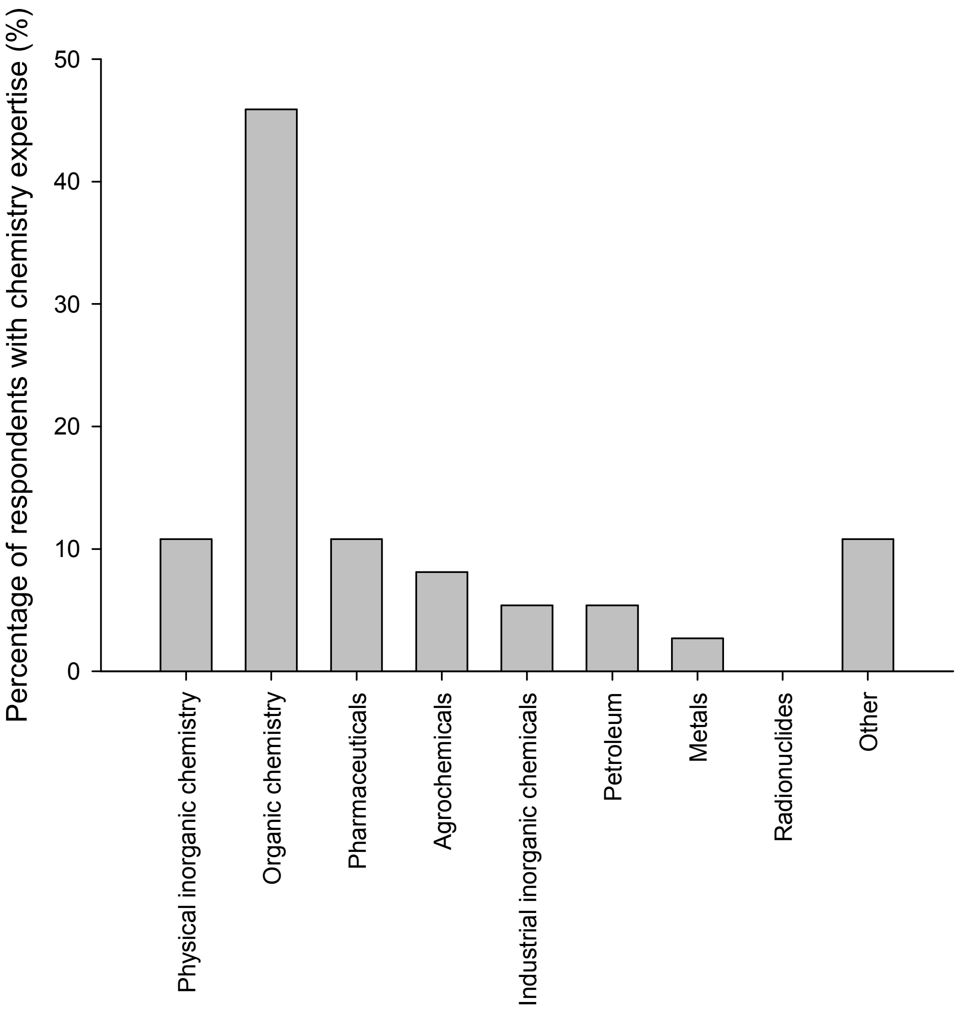
Table 4. Main areas of expertise of life scientists responding to the survey.

Area of Expertise within Life Sciences	Number of life science respondents	Percent of life science respondents (%)
Microbiology	4	1.8
Biochemistry	13	6.4
Cell biology	12	5.5
Physiology	2	0.9
Mammalian toxicology	131	60.1
Ecotoxicology (terrestrial)	3	1.4
Ecotoxicology (aquatic)	19	8.7
Genetics	6	2.8
Computational biology	0	0.0
Pharmacology	9	4.1
Other	16	7.3

The chemists responding to the survey were expert in many different groups of chemicals with the largest proportion being inorganic chemists (Figure 1). There were few trace metal experts. There was no obvious sector effect in chemistry expertise, with 9 of the chemists working in government, 12 in academia, 12 from industry, and 6 working in consultancy.

For the 61 environmental scientists, most were expert in the aquatic environment (40 scientists) with 29 working on freshwater systems and 11 on marine systems. Some considered themselves to be terrestrial experts (16 scientists) and only two were atmospheric scientists. Two environmental scientists indicated "other" expertise. The engineers were either civil or chemical engineers. The risk assessors considered their expertise to be in risk assessment (5 scientists) and on risk management (1 scientist), with five others having a role in giving legal advice or related specialist knowledge on EU directives.

Figure 1. The main areas of expertise of chemists responding to the survey.



2.2.3 Current role of the respondents.

The survey also asked if respondents considered that their current job was within their professional training and expertise that they had identified. Overall, 87 % thought this was the case (i.e., a trained professional in a job appropriate to their training). However, 12 % were not working in a current post that matched their original training or expertise. This indicates that most scientists were currently working within their discipline, and those that were not in an appropriate post (45 respondents) either choose to change career direction (27 respondents) or were currently unable to find a post that matched their qualifications (8 respondents overall).

There was considerable professional loyalty with scientists staying within their profession with 139 scientists (39 % of respondents) being in the profession for more than 20 years, 88 scientists between 10-20 years, and 40 scientists between 5-10 years. Only 37 (10 % of respondents) scientist had ever had a career break away from science, but of these individuals, 13 were forced to take a career break because they could not find a suitable scientific post.

The current posts of respondents were government (77 or 21.4 %), academia (87 or 24.2 %), industry (125 or 34.8 %), and consultancy (67 or 18.7 % of respondents). The main areas of work of the respondents are shown (Table 5). They worked for many types of companies, government and university departments. There was some sector-bias in the responses, and not surprisingly, 60 of the 72 respondents conducting fundamental research came from academia. Similarly, 39 of the 44 scientists performing data collection for regulatory needs came from industry. Risk assessment/management posts were well represented in all sectors except academia; government (29), industry (49), consultancy (20), and academia (4), of the 102 respondents in this category. Only 30 % of all respondents had higher tier management responsibilities such as corporate level decision making. The scientists spend a reasonable time in their post, with 30 % spending between 2-5 years in their current posts, and 34 % spending 5 years or more in their current job.

Table 5. Main purpose of your current post for all respondents.

Main Purpose of current post.	Number of respondents	Percent of respondents (%)
Fundamental or applied academic research	72	20.1
Data collection on hazards for regulatory needs	44	12.3
Occupational health and safety	8	2.2
Risk assessment / management	102	28.4
Policy development and implementation	15	4.2
Allocation of research funding / commissioning of research	5	1.4
Environmental monitoring / protection	8	2.2
Food safety	6	1.7
Drinking water safety	2	0
Air quality	2	0.6
Clinical care	2	0.6
Veterinary care	2	0.6
Clinical trials	3	0.8
Human health monitoring	1	0.3
Public health	4	1.1
Education	13	3.6
Provision of training	1	0.3
Consultancy	40	11.1
Other	27	7.5
TOTAL	357	99 %

The types of substances the respondents are currently investigating and have studied in the past are shown in Table 6. Notably, respondents have worked with several groups of chemicals in their current and past employment. The number of people working on nanomaterials has increased, and is comparable to those working with radioactive substances and some agrochemicals.

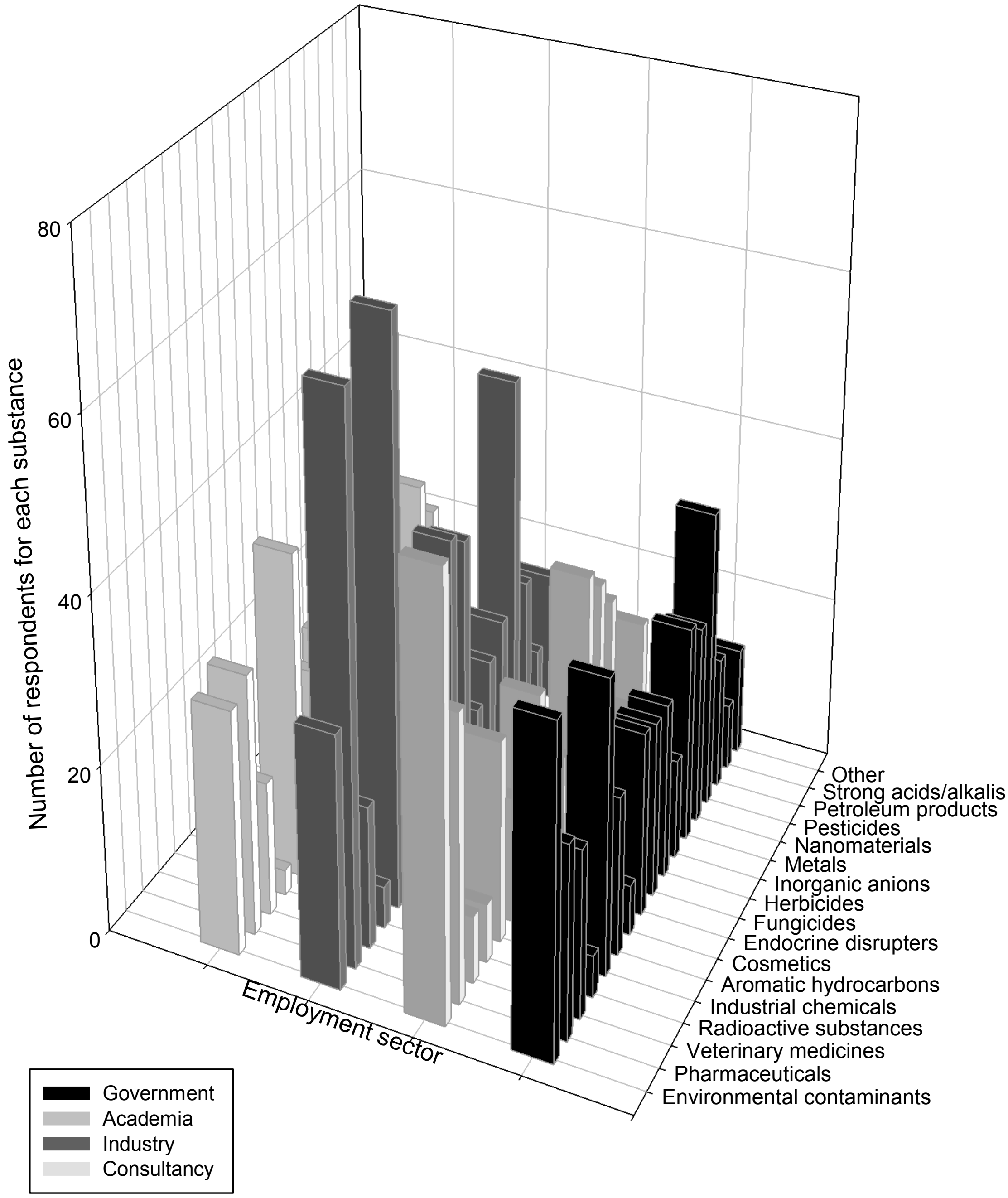
Table 6. Main substances investigated by all the respondents.

Substance	Current Post		Past Employment	
	Number of respondents for each substance	*Percent of respondents for each substance (%)	Number of respondents for each substance	*Percent of respondents for each substance (%)
Environmental contaminants	150	41.8	81	22.6
Pharmaceuticals	155	43.2	79	22.0
Veterinary medicines	61	17.0	55	15.3
Radioactive substances	20	5.6	28	7.8
Industrial chemicals	167	46.5	72	20.1
Aromatic hydrocarbons	78	21.7	49	13.6
Cosmetics	49	13.6	48	13.4
Endocrine disrupters	93	25.9	54	15.0
Fungicides	86	24.0	63	17.5
Herbicides	88	24.5	68	18.9
Inorganic anions (sulphates, halogens)	37	10.3	32	8.9
Metals	93	25.9	65	18.1
Nanomaterials	74	20.6	19	5.3
Pesticides	134	37.3	88	24.5
Petroleum products	66	18.4	47	13.1
Strong acids/alkalis	25	7.0	23	6.4
Other	48	13.4	66	18.4

*Respondents could choose more than one material, therefore % values are per substance.

The types of substances were also analysed by sector (Figure 2). There was generally good coverage of the main substances in government, academia, industry and consultancy. For a few categories, there was some bias reflecting the nature of the chemicals business. For example, industrial chemicals, not surprisingly, were mainly investigated by respondents working in industry. Similarly, this was also the case for pharmaceuticals. For nanomaterials the split was 24, 26, 18 and 6 respondents from government, academia, industry and consultancy, respectively.

Figure 2. The main substances currently investigated by all the respondents by employment sector.



Only a fraction of all respondents currently work "hands on" at the bench with chemicals (94 respondents or 26 %), and 262 respondents (73 %) did no bench work at all in their day to day employment. Of those 94 working at the bench, more than half were academics (60 % of those doing bench work, 26 % from industry). Just over half the respondents acknowledged that they had not performed any bench work in the last ten years (51 %), and 19 % more than 5 years ago. A total of 85 % of respondents did not have recent (< 2 years) bench experience.

About two thirds (218 scientists or 61 %) of respondents indicated that they had some continued professional development (CPD) in their current post, and nearly all of this was theory (e.g., lecture courses/class room work) rather than practical training on instrumentation, or management/leadership training (generic training). However, most of the CPD training was current, having been competed in the last year (74 % of respondents).

Most respondents were content in their current post, in that they were not actively seeking alternative employment (233 scientists or 65 %), but 78 scientists (22 % of respondents) were looking to change their job. The reasons for this were varied, but the main reasons were to gain promotion (30 % of those looking to change job), a higher salary (32 %), or to develop their career in another way (30 %). Short term contracts and job security were an issue for 37 % of respondents looking for alternative employment.

2.2.4 *The working environment and current skills gaps.*

Team working was a strong feature of the work environment with 84 % of respondents indicating that they worked in a team rather than alone, and 47 % of respondents indicated that they had a managerial role in the team. Opinion on whether the size of scientific teams had increased or decreased was varied, with 27 % indicating a decrease, 34 % no change, and 38 % an increase in the last 2 years. Only 32 % of respondents thought that their team would increase in the next 2 years, with most (45 %) indicating that team sizes were likely to stay the same. Teams were multi-disciplinary (52 % of respondents), and about a quarter of teams comprised of scientists from a single discipline (24 % of respondents). Interestingly, 24 % of respondents managed scientists who were not formally recognised as a team. Where teams were multi-disciplinary, the respondents indicated that they were managing mostly life scientists (79 respondents), chemists (58 respondents), or environmental scientists (53 respondents). Physicists (6 respondents), veterinary surgeons (9 respondents), social scientists including policy makers (13 respondents), and medical doctors (15 respondents), tended not to be included in teams. Regulators (18 respondents) and health and safety advisors (20 respondents) were represented in some teams. Respondents were also asked to comment on the current level of specialist technical expertise in their team and current skills gaps in their teams (Table 7). About a third of respondents indicated that practical bench skills featured in their current teams (Table 7), but most did not think these skills were absent. Skills with statistics, risk assessment, and regulatory knowledge featured as skills currently missing from teams. Skills missing under the “other” category included comments mostly related to animal welfare such as *in vivo* experience and animal handling, and also experimental design, and critical thinking. Most thought the current skills would also be needed in the future.

Table 7. The proportions of respondents indicating current skills, and skills gaps in their current teams, and skills needed in the future.

	Current Skills	Missing skills	Future skills needed
Skill	*Number of respondents (% of all respondents)	*Number of respondents (% of all respondents)	*Number of respondents (% of all respondents)
Specialist bench expertise: Practical skills at the bench	129 (36)	10 (3)	109 (30)
Specialist bench expertise: Running analytical instruments	105 (29)	18 (5)	107 (30)
Specialist bench expertise: Specialist protocols/assays	112 (31)	12 (2)	115 (32)
General bench expertise (e.g. lab technician skills)	97 (27)	7 (2)	83 (23)
Veterinary skills	20 (6)	5 (1)	40 (11)
Animal welfare expertise	75 (21)	7 (2)	78 (22)
Medical skills	29 (8)	8 (2)	42 (12)
Statistical skills	101 (28)	30 (8)	167 (47)
Risk assessment skills	204 (57)	30 (8)	239 (67)
Regulatory and policy expertise (rules / regulations / government guidelines / legal)	192 (54)	25 (7)	288 (80)
Data management/analytical skills	194 (54)	16 (4)	217 (61)
Presentation skills	198 (55)	11 (3)	184 (51)
Report writing skills	227 (63)	13 (4)	210 (59)
Mathematical skills	81 (23)	10 (3)	91 (25)
Management skills	139 (39)	16 (5)	183 (51)
Other	17 (5)	23 (6)	18 (5)

*This is the number of respondents who work in a team within each skill category. Responses to more than one category were possible. The percentage values (to the nearest percent for clarity) are the % of all respondents regardless of the whether or not they work in a team.

The perceived causes of the current skills gaps (Table 8) was attributed to inability to recruit staff with the necessary skills, and issues related to staff turnover such as staff not being in the job long enough to master the skill. Insufficient training and staff development also featured, but where training was given the training programmes were usually completed. At least 44 respondents (25 % of those respondents with concerns about missing skills) thought that these current skills gaps posed a threat to the functioning of their organisation; only 27 did not think this was a threat.

Table 8. Perceived causes of the current skills gaps in scientific teams.

Cause of Skill Gap	*Number of Respondents who thought there was a skills gap.
Insufficient training and development for staff	29
Lack of suitable training available from external suppliers	20
Staff have not been in the job long enough	38
Staff leaving	26
Workforce find it difficult to keep up with change	3
Training programmes only partially completed	6
Unable to recruit staff with the necessary skills	51
Other	14

*This is the number of respondents for each category of skills gap, and only those respondents who indicated skills were missing.

Despite the concerns about skills shortages, respondents thought that their organisation was either doing nothing about it, or sub-contracting work outside the organisation to get around the problem (Table 9). Only 42 of respondents thought that their organisation was providing further training. However, respondents gave very mixed views when asked what skill their organisation was most concerned about filling in the next 5 years, with most skills being identified (a few % or less of respondents to each skill), and 40 % of respondents not being able to answer the question (no answer given). This suggests scientific staff are identifying skills shortages, but are not involved in corporate or strategic planning to solve them.

Table 9. What respondents perceive their organisation to be doing about the current skills gaps.

Solution to Skill Gap	*Number of respondents who thought there was a skills gap
Providing further training	42
Changing work priorities	12
Redeploying work within the organisation	14
Sub-contracting	30
Importing expertise from outside the UK	14
Recruiting staff from within the UK	22
No particular action being taken	32
Other	9

*This is the number of respondents for each category of skills gap, and only those respondents who indicated skills were missing.

Current demands for new scientific staff were driven by several issues, with respondents considering the development of new projects or services as being the main driver (188 respondents, or 52 % of all respondents), the introduction of new technology (109 respondents or 30 %), new work practices (80 respondents or 23 %) or changing policy (130 respondents or 36 %) also featured. The need for recognised qualifications/certificates was not considered very important (47 respondents or 13 %).

2.2.5 Dealing with the skills gap in the future

Respondents were asked who they thought should be responsible for filling the skills gap in the medium to long term. Most thought this should be done within their organisation at some strategic level (71 % of all respondents), but also recognised that their team had some collective responsibility for training (40 %), as well as the individual seeking/needing the training (49 %). There was also opinion that the training gap needed to be filled by the higher education system/university sector (42 %), or by government led initiatives (32 %). Most (73 %) thought that their organisation would try to meet the medium/long term skills gap by training up their current staff, or by recruiting new ones (69 %). However, 18 % did not know a solution within their organisation. Respondents gave extremely variable answers to how many staff they thought their organisation would need to recruit over the next 5 years, from one or two staff to 40 staff, and with numerous caveats (e.g., depended on policy, market forces, not possible to predict etc). However, when asked how training within their organisation was likely to be implemented, most thought that it would be formal in house training (88 %) or simply through day to day mentoring in the team (81 %). Fifty five percent thought that CPD/short course events were a likely training vehicle and 81 % indicated that this should be delivered by an external provider. There was also reasonable confidence that the skills gap could be met completely (18 %), or partly (51 %) with their current plans, only 12 % did not think this could be achieved, and 18 % did not know.

Respondents who indicated that the higher education/university sector had a role in providing training were asked to clarify what types of training should be given in the future (Table 10). Notably, more importance was given to CPD courses and professional accredited courses than first degrees. Masters level training being considered as important as CPD events.

Table 10. Role of the higher education/university sector in meeting future skills needs.

Type of training	Number of respondents who considered that HEIs had a role	*% of respondents in favour of each category of training
CPD courses	98	65.8
First degrees, or equivalent (BA, BSc, etc)	85	57.0
Higher degrees, or equivalent, mainly by taught course (MA, MSc etc,.)	102	68.5
Higher degrees, mainly by research (PhD, DPhil, MPhil etc)	90	60.4
Professional accredited courses	111	74.5
Other	6	4.0

*percentages are category specific, and respondents could select more than one type of training.

2.2.6 Recruitment

Scientists use a range of methods to recruit new staff with the "New Scientist" magazine (60 % of all respondents), online resources (43 %) and via professional/scientific bodies (44 %), being the most popular. Recruitment consultants (33 %), national newspapers (21 %) and word of mouth (34 %) were also used. A total of 197 scientists (55 % of all respondents) indicated that they had vacancies to fill over the last 12 months, and of these, 98 scientists indicated that they had problems filling these vacancies.

A lack of suitable applicants, experience, or skills was the main cause of recruitment problems (Table 11). These difficulties applied to all levels and types of posts from junior technicians to senior managers, with no particular post being reported as more difficult to fill than others. The most urgent posts were from different sub-disciplines of toxicology or different types of risk assessor posts (with so many types, comprising < 1 % of response for each). The solution to the recruitment problems within their organisation were mainly to re-advertise the post (69 respondents or 70 % of those with recruitment problems), recruit less qualified staff (34 respondents), promote staff internally (32 respondents), or alter the job specification (25 respondents). Relatively few organisations would turn work away as a result of recruitment difficulties (8 respondents), and would rather sub-contract (12 respondents) or use temping agencies (14 respondents). Increasing overtime was not a preferred solution for organisations (2 respondents). Improving pay and conditions was also suggested (10 respondents).

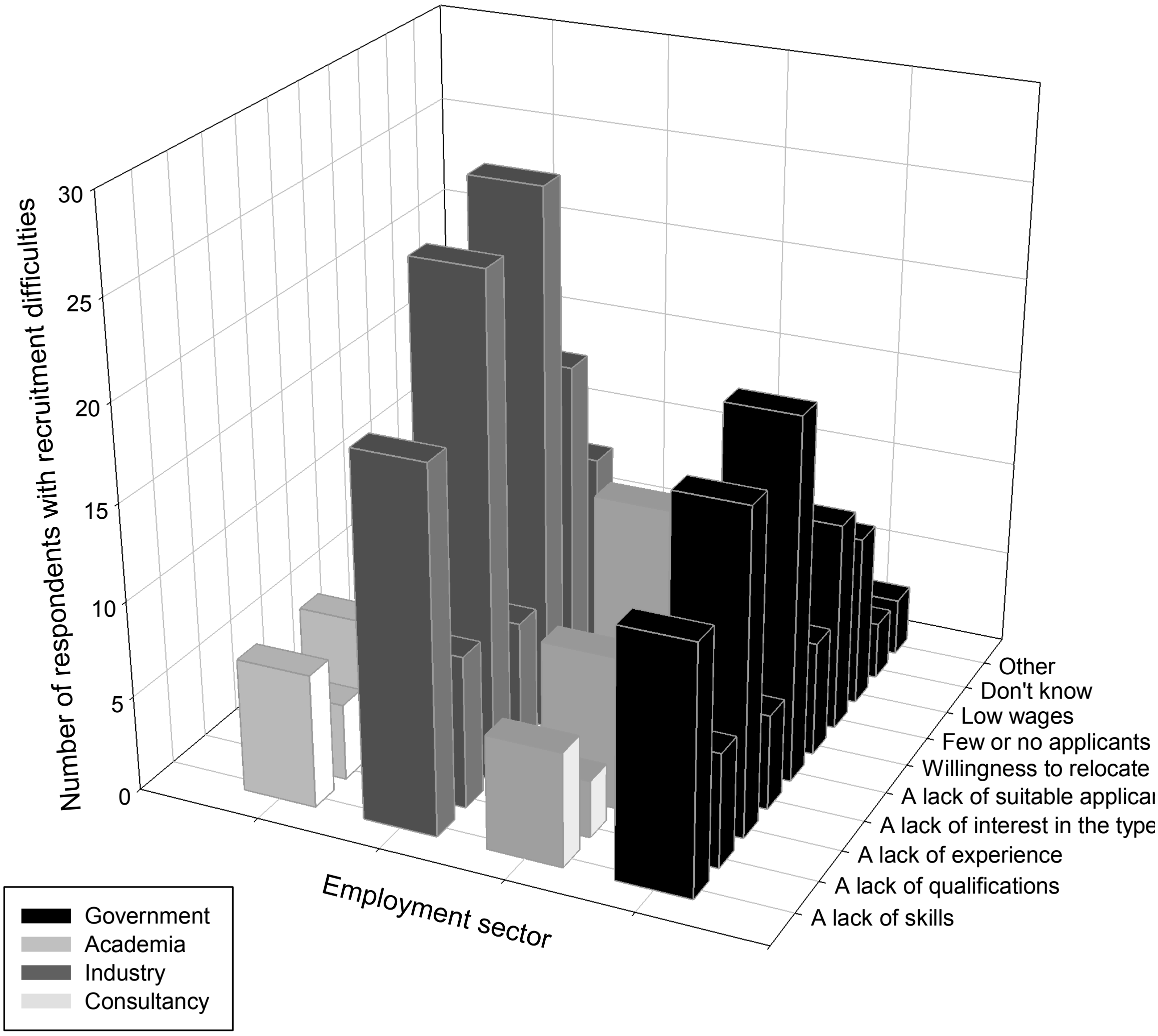
However, the view at the team level of what was actually happening was very different to the organisation/corporate view, with team leaders reporting that work was turned away (18 respondents) and that sub-contracting occurred (30 responses), and with time constraints work was either rescheduled (39 responses) or not completed on time (29 responses). There was a marked concern about long hours, with 66 % of respondents indicating that they worked long hours because of staff shortages. More than half (65 team leaders) thought that their most urgent/hard to fill post would compromise the function of their team in some way. Other perceived barriers to recruitment included insufficient company funds to hire staff (160 respondents or 45 % of all respondents), resource allocation away from recruitment within the company (132 or 37 % of all respondents), and lack of physical space to place new employees (44 or 12 % of all respondents).

Table 11. Recruitment difficulties for the 98 respondents who reported problems with filling vacancies.

Reason why a vacancy is hard to fill	Number of respondents with recruitment difficulties in each category
A lack of skills	46
A lack of qualifications	21
A lack of experience	59
A lack of interest in the type of work	15
A lack of suitable applicants	71
Attracting suitable applicants to relocate to the local area	32
Few or no applicants	34
Low wages	18
Don't know	5
Other	5

Respondents considered that recruitment was generally getting more difficult, with 39 % of all respondents indicating recruitment had got harder or much harder over the last 5 years; only 0.3 % thought it was easier. Recruitment was also analysed by sector (Figure 3). There were generally more recruitment difficulties in industry than the other sectors. A lack of suitable applicants and a lack of experience was a key issue for all sectors.

Figure 3. Recruitment difficulties in the different sectors of employment.



2.2.7 Graduate and post-graduate skills

Respondents were asked their view on the content of toxicology (and related) degrees at both undergraduate and postgraduate level, and on the skills-base of graduates. Only 32 % (115 of all respondents) considered undergraduate training in toxicology and related topics to be satisfactory, or very satisfactory (7 respondents, or 2 %). A quarter of respondents had concerns (unsatisfactory, 23 %; very unsatisfactory 4 %), but 36 % (131 respondents) did not feel able to comment. Respondents were asked why they thought educational training was satisfactory or unsatisfactory; 36 % (132 of all respondents) considered a lack of practical training as an issue (only 6 % did not). Skills that were perceived as missing from undergraduate training in toxicology included:-

- Computational biology
- Critical analysis of data and report writing skills
- Design of toxicological studies
- Histopathology techniques, microscopy and cytology.
- Medical/scientific writing
- Molecular toxicology
- Practical experience of toxicology in general

However, a large proportion of respondents did not feel able to comment (42 % don't know).

A similar picture emerged for masters level training with 89 (24 % of all respondents) regarding skills being missed from masters level training (only 11 % did not, 59 % "don't know"). There were many practical skills listed as missing by respondents including the ones identified at undergraduate level, plus:

- animal handling and welfare
- whole animal experience/physiology
- risk assessment skills
- specialist computational skills such as toxicokinetics
- practical statistics
- regulatory toxicology
- specialist knowledge on some body systems, reproductive toxicology, neurotoxicology, in particular.
- Histology and animal anatomy

Comments also noted a lack of time to teach practical skills and also a lack of academic toxicologists to train them. Academic providers were asked about toxicology training and the provision of related subject material such as chemistry for biologists; 32 % considered that training in chemistry and related aspects was inadequate. Respondents were asked to give specific examples, and comments indicated either all areas of chemistry, analytical chemistry, environmental chemistry, or simply a lack of co-ordination in the way chemistry and physics was taught to life scientists. Some respondents considered that physics was no longer taught at all, and many noted the closure of UK chemistry departments as an important factor in the ability to provide multi-disciplinary training.

Despite the above problems with graduates, 173 (48 % of all respondents) would employ a recent graduate in their organisation, although nearly half (47 %) would not. The view on graduate skills by respondents is outlined (Table 12). Overall, practical training and maths was a key concern. Poor writing skills were also noted.

Table 12. Rating of the skills of recently qualified toxicology-related graduates by the 173 respondents who would employ a recent graduate (% of respondents in each category).

Skill Area	Very Good	Good	Satisfactory	Poor	Very Poor	Don't know
Specialist technical skill	2.9	13.3	30.6	9.2	1.7	37.0
General practical/bench skills	1.7	8.1	22.0	15.0	1.2	47.4
Knowledge of theory	5.2	26.6	28.3	2.9	0.0	32.9
Mathematical skills	1.2	13.3	28.9	15.0	1.2	36.4
Writing skills	1.7	14.5	27.2	20.8	1.7	30.6
Communication skills	3.5	20.2	28.9	9.8	2.3	31.2
Confidence	2.9	23.1	34.7	3.5	0.6	31.8

Overall, when asked if graduates were leaving university with the right mix of theory and practical skills, only 10 % (17 scientists) of those who would employ a graduate said yes, 23 % (40) asked for more practical, and 19 % (33) for more practical and theory, only 4 % (6) thought that more theory alone was needed.

2.2.8 Training and training others

Respondents were asked about the current training methods used by their organisation, and also whether or not they had personally been involved in training others. In house training (244 or 68 % of all respondents), CPD/short courses (258 or 72 %), and less formal mentoring (253 or 70.5 %) was used. Accredited training was more limited (105 or 29 %), and only 6 % of all respondents (20 scientists) reported no training activities in their organisations. Where training did occur, regardless of type, respondents thought generally that training was effective or very effective (70 % or more of responses). Only 1-2 % of respondents considered the above training approaches ineffective in their experience. However, 50 % of respondents indicated that staff would need further training on additional courses.

Only 42 % (154 of all respondents) were involved in training others, and only 27 % (53 respondents) in an aspect of toxicology. However, this training experience was not current with 42 % of those involved in training having done so more than 5 years ago, and only 5 % had been involved in a training event in the last year. The types of training respondents had been involved in are indicated in Table 13.

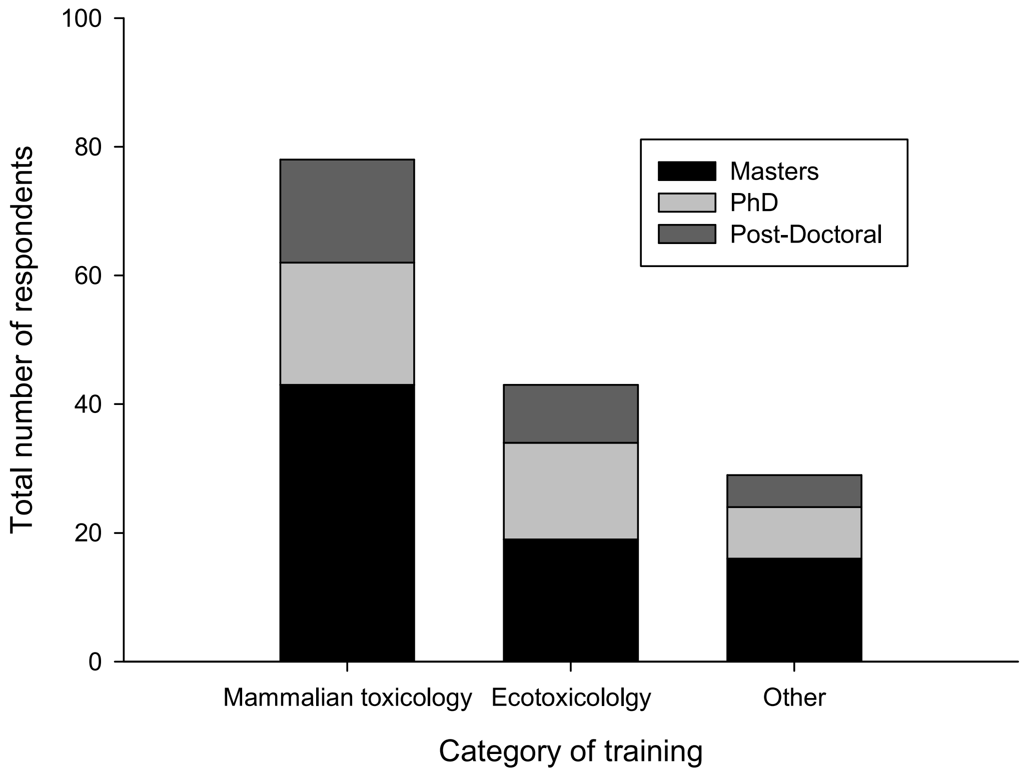
Table 13. Training events that respondents have taught in the last 2 years.

Type of Training	*Number of respondents
A level	4
Undergraduate	35
Postgraduate	79
Continuing Professional Development (CPD) courses	53
In-house training/on the job training	134
Other	7

*respondents could report training in more than one category.

Academic training providers were additionally asked to give opinion on how toxicology was delivered in undergraduate degrees and in specific aspects of training in academia from A-level through to post-doctoral level. Toxicology is generally not taught as a degree, with only 5 academics (14 % of academics) teaching a specific toxicology degree. Most academics teach a toxicology module (20 academics, 57 %) on another life science degree (e.g., a toxicology module in a biomedical sciences degree). Some degrees only have a few lectures (not a module, 43 % of the academics teach this way). However, academics and other training providers were active in post-graduate training in toxicology subjects (Figure 4). In addition to this they also taught many other subjects at masters level (cell biology, genetics, occupational health etc) and also supervised PhD students who were studying other topics (e.g., ecology, physiology, environmental chemistry). These academics were also involved in post-doctoral training, which tended to be highly specialised and extremely varied (e.g., the use of zebrafish in drug discovery, course on ISO 109993 standard, occupational toxicology case study).

Figure 4. The total number of respondents involved in training mammalian toxicologists or ecotoxicologists at post-graduate level in the last 2 years.



The bench skills taught at all levels from A-levels to on the job training are outlined (Table 14). Not surprisingly, most of the basic laboratory skills are taught at A-level and degree level. Training in the use of large analytical instruments is generally weak with most training occurring at postgraduate level. Training in animal handling is also poorly represented, and training on invasive surgical procedures is very infrequent.

Table 14. The number of respondents teaching particular bench skills.

	Not applicable, theory only.	Basic laboratory skills	Using large analytical instruments	Animal handling	Surgical procedures	Other
A level	0	2	0	0	0	0
Undergraduate	15	15	2	6	2	1
Postgraduate	37	26	17	11	7	6
CPD course	36	0	2	3	1	2
In house/on job training	84	30	18	10	6	14

The motivation for respondents being involved in the training of others was generally not commercial (only 13 % did so specifically for income generation); most were involved to help keep skills within their organisation (55 %) or to train new staff (68 %). Some considered it a professional duty to help fill the skills gap (44 %), while others did so as a professional courtesy following an invitation from a colleague to participate in a training event (42 %).

2.2.9 Uptake of toxicology courses by students

Finally, academics were asked specifically about student uptake of toxicology courses. Most academics (55 or 63 % of the academics) did not know their institutional figures for student uptake of courses, but 17 % thought uptake had remained the same, 11 % thought it had increase, and 6 % considered a decrease in uptake by students. At least half of the academics did not know if their institution had stopped providing toxicology related courses in the last 5 years (50 %), 42 % indicated no loss of provision, and 6 % indicated their courses had closed (5 academics). Where courses were closing, this was attributed to lack of interested students. This apparent lack of interest was attributed to low subject awareness because the topics are not taught at A-level. Academics were also asked about student perception of toxicology, and why students may not choose these topic areas. None thought it was perceived as too hard or with too much math or chemistry, and none were concerned that students were avoiding the topic for ethical reasons (e.g., animal experiments).

3.0 Discussion of survey findings

3.1 Types of respondents and their expertise

The respondents were from all age ranges in the profession and with a reasonable balance of male to females (2:1 roughly), indicating that the toxicological sciences are not in gender balance, and steps need to be taken to address this in a similar way to that in the medical profession (e.g., Riska, 2001). This gender imbalance was evident in government, academia, industry and consultancy; suggesting a generic issue for all career paths. It is noteworthy that the gender imbalance is the reverse in the student survey below and in graduate entry statistics for toxicology/pharmacology (more females than males), suggesting that less females are going into the career path on graduation. For those at work, the distributions of age ranges for both males and females were similar, suggesting that women were not leaving science early; apart from after the age of 60 where there were proportionally fewer females (reflecting retirement ages). The 358 respondents can therefore be considered a broad sample of the professions. Most of the respondents were white (88 %), and with only 2 % or less of other ethnic groups, this suggests these groups are not working in this area of science (represented below the proportion in the UK population). This is perhaps to be expected, given that non-white ethnic groups are often poorly represented in higher education (e.g., Bhattacharyya et al., 2003), and are therefore not likely to also go forward in this profession. Nonetheless, the scientists are a loyal work force, and tend to remain loyal to their discipline. The fact that 96 % had either a masters, or PhD (or both), indicated that they had some personal experience of formal training to draw on when answering some of the questions in the survey. The survey also captured the main target audience since most were life scientists including many toxicologists (70 % of the life scientists responding), environmental scientists or chemists. There was a poor response from engineers and physicists, but this was most likely due to sampling bias, because the survey was deliberately targeted at toxicologists and chemists. However, at least 200 nano-scientists were invited to respond to the survey, and physicists/engineers are present in this community.

Capturing data on the expertise and disciplines of the respondents also gives a useful snapshot of how the professions are working. Most of the toxicologists were mammalian toxicologists, with relatively few ecotoxicologists, and even fewer experts on terrestrial ecotoxicology. There was a sector bias with most of the mammalian toxicologists being in industry, and the ecotoxicologists in academia. This should be addressed so that training in mammalian toxicology is maintained in HEIs, and there may be a need to encourage ecotoxicologists to take posts in industry to balance those in academia. Similar to ecotoxicology expertise, the environmental scientists were mostly aquatic ecosystem experts. This overall balance of toxicologists appears to reflect the appropriate diversity of expertise one would expect given the historic regulatory drivers for the assessment of chemicals. The priority has always been in relation to human health which has a requirement for significant mammalian toxicity testing, and this is likely to continue. The requirement for ecotoxicologists and chemists should not be neglected. Most point source emissions from manufacture are direct to aquatic systems. Best practice and end-of-pipe controls have reduced the amount of untreated chemicals entering these systems, but the persistence of many chemicals in the environment and diffuse pollution has meant that there has been ongoing need for research into aquatic toxicology.

Life scientists from other disciplines were less well represented and some of this may be the deliberate survey bias towards toxicologists. Nonetheless biologists from all areas of animal and cell biology were invited (e.g., members of the Society for Experimental Biology). There appears to be a very low number of physiologists (e.g., needed to support animal work). The new fields of biology like computational biology have not yet worked their way into the chemical hazard and risk assessment field. This will probably happen in the near future given the potential applications of systems biology to toxicology and environmental protection (review, Handy 2008). The chemistry community is generally well represented, but the number of experts on metals was surprisingly low, and no radiation experts responded to the survey from the radiochemistry community (although a few biologists with radiation expertise did respond). This analysis may therefore identify current expertise gaps (not enough physiologists, inorganic chemists working on metals, radiation experts) in the supporting area of chemicals safety and risk assessment. These gaps may arise from long term changes in the academic community (e.g., the perception that there is less funding for studies on metals over the years), although these perceptions are hard to quantify from research council or other data. Expertise on terrestrial systems is also less well represented than that for aquatic systems for environmental assessments.

3.2 Current roles of the respondents

Most scientists were working in a role that matched their original training (discipline loyalty), and there was a fairly even mix of representation from government, academia, industry and consultancy. Analysis of their main job (Table 5) gives a picture of how many scientists are supporting each of the main areas involved in chemical safety and risk assessment. Staff involved in risk assessment and risk management were well represented, but there was a relatively small proportion of staff involved in collecting regulatory hazard data. This perhaps reflects overall concerns on shortages of staff with laboratory skills to collect data. This was also reflected in the current levels of bench work of the respondents (only 26 %), suggesting that the capacity to conduct bench work is a weak area in the overall process. Environmental monitoring was poorly represented in the survey, which raises questions as to whether there are enough people working on the ground to monitor compliance, or indeed to measure unexpected changes in environmental quality. Academic research was the second largest group of job types, indicating that there is a reasonable scientific base for the more applied regulatory areas to draw from. Consultancy was also well presented, and together with academics, represents a good lobby of independent scientific advisers for government and industry to use.

There was generally good coverage of the main types of substances that need regulation (Table 6), and the number of people working on nanomaterials was close to those working on more traditional chemicals like herbicides. Radioactive substances and expertise on inorganic anions was limited, but the former is at least regulated by other agencies (e.g., Health Protection Agency). The number of scientists working on each category of substance has generally increased, with respondents indicating that they work on more chemicals now than in the past (suggesting increased work load/person, not more scientists). The workforce was mainly content (only 22 % looking for a new job), and the reasons for seeking alternative employment were common to other professions outside of science (e.g., to seek promotion). Scientists were not leaving due to poor working conditions, and although team leaders considered long hours to be a threat, it seems that loyalty to the discipline/professionalism is more important than the current difficulties in working conditions to most scientists in the survey.

3.3 Working environment and skills gaps

The sizes of scientific teams did not appear to be under threat, and half of the respondents were involved in multi-disciplinary team working with biologists, chemists, and environmental scientists. An analysis of the current skills, and future skills needs (Table 7) indicated that skills on risk assessment and regulation were lacking, despite being the most evident skill in current teams. This suggests that while many respondents were involved in risk assessments, they also thought that more were needed. One must take a European or global perspective on this issue, because although a UK-based scientists may be doing the risk assessments, their work will be applied to a much broader market places in the EU and elsewhere.

The regulatory requirements for chemical risk assessment under REACH are a probable cause for this concern. At the close of the pre-registration period, 145,000 substances had been pre-registered by approximately 65,000 companies. Although some substances given different identities at pre-registration will in time prove to be the same, this will still leave a very large number of chemicals requiring assessment. Other developing policy agendas that will require risk assessment are the EU Environment and Health Agenda, hazard identification for nanomaterials and biomonitoring initiatives. Toxicity testing is also likely to be in high demand in order to satisfy registration requirements under REACH.

To achieve the registration targets that have been set there will have to be wider acceptance of intelligent testing strategies that allow a range of approaches to assess the risks inherent in the chemicals under investigation. These allow for rapid screening of chemicals in order to identify those substances that require further testing and risk management. Currently approximately 70 % of animals used in toxicity tests are needed for just three animal testing requirements – two-generation reprotoxicity, developmental toxicity and the mutagenicity *in vivo* study. This also accounts for approximately 70 % of the costs involved with animal testing. To date no robust, validated alternatives to these tests are available (Chemical Watch, 2008/09). When environmental testing of pharmaceutical products was introduced under the European Medicines Agency (EMEA) in 2007 there was a 10 % increase in market demand in the USA and Europe for testing. It put the industry under considerable strain worldwide and took two years for contract research organisations to adjust. It was not laboratory space that limited growth, but lack of experts (Chemical Watch, 2009). Risk assessment of nanomaterials is a potential concern. The chemical industry is increasing its own research into the possible hazards of nanomaterials since the expectation is that mandatory tests are likely to be imposed on production and application in some jurisdictions, if not all in time. Even if the industry carries out the tests, experts will be needed to assess the validity of the testing regime and the conclusions drawn (e.g., discussion on test methods for nanomaterials, Crane et al., 2008b) A sub-group of the REACH Competent Authority forum is currently considering whether changes to the Regulation may be necessary to address more accurately the risks of nanomaterials.

Bench skills were also identified as missing skills, although not regarded as important as missing risk assessment skills. The biggest sub-category was the ability to run large analytical instruments. The reasons for this are curious, as most manufacturers will usually provide a training event with equipment installation. It is therefore logical to assume that employers are either not taking advantage of this training in the first place (not likely), or failing to renew the instrument-specific training with staff turnover. Statistical skills were also missing, with nearly half the respondents being concerned that this was an important skill that the team would need in the future. Opinion was diverse on the causes of the perceived skills shortage (Table 8) and aspects relating to staff turnover were the main issue, but this contradicts the perception of loyalty of current staff. One possible explanation of this contradiction is that new graduates (younger staff) are not being as loyal to the profession as established scientists.

There was also a mismatch between the respondents view on the organisation (company) position on dealing with the skills shortage (Table 9) compared to what was happening within scientific teams. This mismatch needs further investigation, on the one hand organisation policy was generally perceived as being to accept as much business as possible; and use sub-contracting if work loads are too high. However, this does not seem to be happening at the team level where long hours were the main threat. This is consistent with the view that new projects and services are the main drivers of the skills shortage.

3.4 Dealing with skills gap in the future and role of higher education

Overall, the community feels a shared responsibility for training, with significant emphasis on in house training and mentoring within teams, but with also some commitment by the education sector and government to improving skills in the medium/long term. There was no clear opinion on how many new staff would be needed in the future (too much uncertainty to predict), but most thought that their organisation/company would use training programmes (a combination of in-house, external CPD events) to ensure staff were properly trained. For external training by the education sector, significant emphasis was placed on masters and CPD training by respondents. The latter is consistent with enterprise initiatives at many Universities, but the masters provision is worrying. This is usually expensive to run and the specialist nature of masters training often results in only a handful of students on each course. Scientifically, this offers an excellent training opportunity for the student, but is not financially viable for most Universities in the long term. If the community wants more masters level scientists, then a long term subsidy of HEIs or sponsorship of students will be needed. A high value was also placed on professionally accredited courses, but there are few undergraduate degrees of this kind on offer (see Table 22 below) and post-graduate provision on this accredited aspect could also be improved. The higher education sector also needs to continue its provision of PhD level scientists.

3.5 Recruitment and graduate skills

The survey results indicated all the usual methods of recruitment advertising, but a lack of suitably qualified applicants was the overwhelming view of the main problem with recruitment (Table 11). This suggests a fundamental problem; we are not training staff with the right skills/qualifications for the job. It is not possible to determine from the survey results exactly where the problem originates, but it is likely to be the higher education sector (not training the right type of scientists). There were general concerns that academia was not providing enough practical training, education in maths and statistics, or scientific writing. This is contrary to the facts, as most science degrees have mandatory statistics courses and transferable skills modules (oral communication, writing skills, etc.). It would therefore appear that this undergraduate training is not being effective after graduation, and on entering the work place. About half the respondents would not employ a fresh graduate in their organisation, and prefer to take more qualified post-graduates.

There is clearly a credibility gap between what the higher education sector is providing at undergraduate level, and what working scientists think is needed. However, perhaps less weight should be put on the views of the scientific community given that a large proportion opted for a “don’t know” response to questions on graduates. Many scientists also had no recent experience of training others, and when this did occur it was mostly in house/on the job training (Table 13). An alternative view is that the survey respondents are being accurate about opinion on higher education. For example, post-graduate training is less in ecotoxicology compared to mammalian biology (Figure 4) and this matches up with the current roles of working scientists (mostly mammalian toxicologists, Table 4). The lack of undergraduate training with analytical equipment (Table 14) also matches up with the perception of this skills shortage in the work place. Perhaps a more worrying concern is that 63 % of academics did not know what was happening with course provision at their own institution. This indicates that academics are either unable to find such information on strategic planning of courses, or are not involved (i.e., just delivering what one has been asked to teach). This situation must change if the academic community is to be able to respond to the work place needs in an effective way in the future.

4.0 Results of undergraduate and A-level student centred mini-survey

There were 90 respondents to the student survey. Of these, 57.8 % (52 students) were studying for A-levels/AS-levels or equivalent and 42.2 % for a first degree or equivalent (38 students). The questions on demographics were not answered by all the students, of those who did answer 26 were male and 50 were female. The responses were mainly from white ethic groups (68 students), 2 Asian, 1 Chinese, 1 mixed race, and 2 “other ethic origin” (unspecified). The average age of respondents was 20 years old, with ages ranging from 17-38 years.

4.1 Current Study of A-Level students

Nearly all of the A-level students were in their second year (51 students), with only 1 student in the first year. Most of the A-level students had submitted a UCAS form with a view to attending University or other HEI (45 students, 88.2 % of all A-level students), only 6 students had not. The A-level survey was targeted to students doing one or more science A-levels, and the types of A-levels being done by the students are shown (Table 15). Biology, chemistry, physics and maths remain popular. Environmental science was poorly represented (2 students) and few students were choosing a business-related combination (e.g., business studies or economics with a science).

Table 15. A-levels being taken by current A/AS-Level students. The % responses are the percentage of A-level or AS-level students selecting that particular topic. Students could do more than one topic.

Topic	Number of respondents at A-level	% of respondents at A-level	Number of respondents at AS-level	% of respondents at AS-Level
Applied Science	0	0.0	0	0.0
Art and Design	1	2.2	2	4.4
Biology	26	57.8	19	42.2
Business Studies	1	2.2	1	2.2
Chemistry	33	73.3	23	51.1
Computing	1	2.2	1	2.2
Design and Technology	0	0.0	1	2.2
Economics	0	0.0	0	0.0
Electronics	0	0.0	0	0.0
English Language	0	0.0	0	0.0
English Literature	3	6.7	5	11.1
Environmental Science	2	4.4	2	4.4
French	3	6.7	2	4.4
Further Mathematics	3	6.7	2	4.4
General Studies	23	51.1	18	40.0
German	1	2.2	2	4.4
Geography	7	15.6	8	17.8
Geology	0	0.0	1	2.2
History	5	11.1	4	8.9
Human Biology	8	17.8	7	15.6
Mathematics	21	46.7	18	40.0
Music	0	0.0	1	2.2
Physics	12	26.7	8	17.8
Psychology	8	17.8	10	22.2
Pure Mathematics	0	0.0	0	0.0
Science in Society	0	0.0	0	0.0
Sociology	2	4.4	1	2.2
Statistics	0	0.0	0	0.0
Other	6	13.3	12	26.7
I am not taking any A-levels/AS-Level	0	0.0	2	4.4

4.2 Future study of A-Level students

All of the 45 students doing A/AS-level studies who had submitted a UCAS application had received an offer from an HEI, and 40 of these students had decided what offer to accept as a “firm offer”, and which one to keep as an insurance offer. For most students both the firm offer (35 out of 45 students) and the insurance offer (32 out of 45 students) were science-related degrees. Students were choosing degrees with titles in the life sciences, chemistry, and arts subjects, but not toxicology. The reasons for choosing a degree topic were mainly driven by enjoyment or personal interest in the topic, only 6 students had identified the degree as part of a specific career path (e.g., doing medicine because the student wants to be a doctor). The types of degrees accepted are shown in Table 16. Toxicology and toxicology-related degrees do not show at all, with biology/biological sciences, medicine, chemistry, biomedical sciences, and mathematics being the most popular. Notably, despite physics being a reasonably popular A-level topic, very few followed this up in their degree offer (2.9 %). The uptake of environmental biology and environmental chemistry degrees was also weak.

Table 16. Types of Degrees that were firmly accepted by A-level students with offers.

Degree Topic	Number of A-level respondents	% of A-level respondents
Toxicology	0	0.0
Other degree with toxicology in the title (e.g. Biomedical Sciences (Forensic Toxicology))	0	0.0
Joint degree with Toxicology in the title (e.g. Toxicology with Human Biology)	0	0.0
Biology/Biological Sciences	7	20.0
Environmental Biology	1	2.9
Biochemistry	0	0.0
Biomedical Sciences	4	11.4
Joint degree involving Biology or Biological Sciences, but not Toxicology	0	0.0
Chemistry	5	14.3
Environmental Chemistry	0	0.0
Joint degree involving Chemistry, but not Toxicology	1	2.9
Forensic Science/ Forensic Chemistry	1	2.9
Health and Safety Management	0	0.0
Physics	1	2.9
Medicine	8	22.9
Veterinary Medicine	1	2.9
Mathematics	4	11.4
Engineering	2	5.7
TOTAL	35	100 %

The reasons why toxicology degrees and environmental science degrees are not being taken up is related to student's knowledge of the science disciplines. Only 23 of the 45 UCAS students had heard of the subject of toxicology before, similarly for environmental risk assessment (26 students) and regulatory toxicology or pharmacology (22 students). Students were aware of the topic of environmental chemistry (35 students), but few had heard of ecotoxicology (7 out of 45 students). However, the main reason for not choosing a toxicology-related degree, or environmental chemistry degree appeared to be that students simply wanted to study other topics (Table 17), although 27 % of students were also unaware of the availability of specialist degrees in toxicology or environmental chemistry. Some students had concerns that their A-level choices would not equip them for such degrees, and some were concerned about the chemistry content. Concerns about maths and animal ethics were less important.

Table 17. Reasons why A-level students do not choose a specialist degree in toxicology, or environmental chemistry.

Reason	Number of respondents
Topics related to Toxicology and Environmental Chemistry are not taught at A/AS-level.	7
I lack knowledge regarding the availability of specialist Toxicology and Environmental Chemistry degrees.	10
Specialist courses in Toxicology or Environmental Chemistry are not offered at the University I want to attend.	4
The A/AS-levels I am studying do not qualify me for entry onto specialist Toxicology degrees.	4
I applied but I do not meet the entry criteria/points required.	0
I am worried about the Chemistry content of those courses.	7
I am worried about the Mathematical content of those courses.	4
I am concerned about the difficulty of specialist Toxicology courses.	3
I am concerned about aspects of Toxicology courses (e.g. working with animals).	4
I want to study another subject.	35
Other	0

A-level students were also influenced by factors other than topic or course-content, with parental pressure being very influential (11 students) or quite influential (26 out of 44 students). Advice from peers/friends was also quite influential (24 students) and careers advice from teachers (21 students), but advice from external careers advisors was less important (for 28 out of 44 students this had no influence at all). Most students found the undergraduate prospectus to be quite influential (18 students) or very influential (22 out of 44 students). The media was not influential at all for more than half (25 out of 44 students). In terms of the "very influential" category the undergraduate prospectus was the most important factor, and twice as important as parental or careers advice from teachers.

4.3 Undergraduate student results

Of the 38 undergraduates who responded, all were in their final year, and most were studying subjects with their main base in biology/biological sciences (19 students), environmental chemistry (9 students), chemistry (4 students), biomedicine (1 student), and other topics (5 students). None were studying toxicology, veterinary medicine or physics as a main topic. The main themes of their degrees are indicated in Table 18, and all were studying BSc (Hons) full time (no part-time students) over 3 years, except 5 students doing a 4 year degree. Work placements (1 student) and work based learning (2 students) was poorly represented, with most (30 students) not doing any work place-related activity during their degree.

Table 18. Degree subject area of undergraduate respondents

Degree Subject	Number of respondents	% of undergraduate respondents
Toxicology	0	0.0
A degree with toxicology in the programme (e.g. Biomedical Sciences (Forensic Toxicology))	2	6.1
Joint degree with Toxicology in the programme (e.g. Toxicology with Human Biology)	1	3.0
Biology/Biological Sciences	12	36.4
Environmental Biology	5	15.2
Biochemistry	0	0.0
Biomedical Sciences	1	3.0
Joint degree involving Biology or Biological Sciences, but not Toxicology	2	6.1
Chemistry	4	12.1
Environmental Chemistry	5	15.2
Joint degree involving Chemistry, but not Toxicology	0	0.0
Forensic Science/ Forensic Chemistry	0	0.0
Health and Safety Management	0	0.0
Physics	0	0.0
Medicine	0	0.0
Veterinary Medicine	1	3.0
Total	33	100 %

The awareness of disciplines had improved compared to A-level students, by the final year all degree level students had heard of toxicology, most knew of ecotoxicology (28 out of 32 students), environmental risk assessment (30 out of 33 students), and environmental chemistry (31 out of 32 students). Less were aware of regulatory toxicology or pharmacology (22 out of 32 students).

Students were asked about toxicology or environmental chemistry modules within their degrees. Twenty one students indicated their degree contained a toxicology module, and 12 an environmental chemistry module. However, these were mainly option modules, not core modules, with only 2 students actively choosing toxicology modules, and 9 choosing the environmental chemistry modules. Only 5 out of 25 students had considered taking a more specialist degree in these topics when starting university, and the reasons for not choosing a specialist degree (Table 19) were similar to those of the A-level students.

Table 19. The reasons why undergraduate students do not choose a specialist degree in toxicology or environmental chemistry.

Reason	Number of respondents
Topics related to Toxicology and Environmental Chemistry were not taught at A level	8
I lacked knowledge regarding the availability of specialist Toxicology and Environmental Chemistry degrees	11
I wanted to study another subject	20
Specialist courses in Toxicology were not offered at the University I wanted to attend	6
The A-levels I studied did not qualify me for entry onto specialist Toxicology degrees	3
I applied but I did not meet entry criteria/points required	0
I was concerned about the difficulty of specialist Toxicology courses	4
I was worried about the Chemistry content of those courses	8
I was worried about the Mathematical content of those courses	8
I was concerned about aspects of the course (e.g. working with animals)	0
Other	1

4.4 Learning experiences during the degree

Undergraduate students were asked about their learning experience during their degree, especially in the context of the amount and type of practical work. Undergraduates were asked to estimate the percentage of time spent on practical work during their degrees, and responses ranged from 5 % to 50 % of the time. At least half the students (51 % of replies) indicated that the theory content of their course was higher than they had expected. The undergraduate were exposed to a variety of practical laboratory skills, data analysis skills, and writing skills (Table 20). The veterinary and medical skills were poorly represented only because few students studying these topics responded to the survey. However, despite a variety of life science students responding, only 15 % had gained any animal welfare experience. Students were also given the opportunity to make other comments on practical work, and these comments were mainly positive. Comments included enjoyment of field work, recognition that adding more practical work would have been difficult with the current number of theory lectures, and that practical work reinforced theory. A few students considered that they had been mislead by tutors, or misunderstood the expected amount of practical work in their degree. For some students the dissertation was critical for learning practical skills. Students were also asked what topics they would like to see more theory and practical tuition on. Only 34 % of the students considered that there were additional practical skills they would like to learn, and these were very specialist and subject-specific skills (e.g., skills in making gene libraries, bioinformatics, environmental impact assessment) rather than generic laboratory or field work skills.

Table 20. Skills that undergraduates considered they had acquired during their degrees.

Degree Subject	Number of respondents in each category.	% of undergraduate respondents in each category.
Practical skills at the bench	28	84.8
Running analytical instruments	20	60.6
Specialist protocols/assays	14	42.4
General bench experience	25	75.8
Veterinary skills	1	3.0
Animal welfare expertise	5	15.2
Medical skills	1	3.0
Statistical skills	25	75.8
Risk assessment skills	24	72.7
Data management/analytical skills	25	75.8
Presentation skills	28	84.8
Report writing skills	30	90.9
Mathematical skills	19	57.6

Undergraduates were also asked about the types of chemicals they had studied (whether theory or practical), and students generally had a broad experience of many different types of chemicals including nanomaterials (Table 21).

Table 21. Chemicals that undergraduates considered they had studied during their degrees.

Degree Subject	Number of respondents in each category.	% of undergraduate respondents in each category.
Environmental contaminants	27	81.8
Pharmaceuticals	10	30.3
Veterinary medicines	2	6.1
Radioactive substances	19	57.6
Industrial chemicals	21	63.6
Aromatic hydrocarbons	2	75.8
Cosmetics	6	18.2
Endocrine disrupters	22	66.7
Fungicides	14	42.4
Herbicides	18	54.5
Inorganic anions (sulphates, halogens)	23	69.7
Metals	22	66.7
Nanomaterials	11	33.3
Pesticides	21	63.6
Petroleum products	16	48.5
Strong acids/alkalis	19	57.6

Students had confidence in their lecturers, and considered that theory was being taught by leading experts in the field who were also active researchers/practitioners (79 % of undergraduates). Only 3 % considered that they were being taught by a tutor who was simply teaching from a book (not a practitioner in the field), while 15 % considered their tutors to be a mixture of these extremes. There was slightly less confidence on practical teaching with only 52 % of students considering their tutor to be an active researcher/practitioner, and with 36 % indicating a tutor with a mixture of research experience and use of text books. Students were not concerned about being taught practical skills by demonstrators or post-graduates (6 % of responses were concerned). Students were reasonably confident about recalling and using theory knowledge. Students were also asked to score their confidence at particular practical skills (e.g., solution handling, using instruments, plotting graphs, analysing data etc). Students were reasonably confident in all these areas including data analysis/statistical skills. Confidence was low in blood sampling and animal handling skills because students had not been taught those skills. Students had poor confidence in being able to recognise pain, suffering, or distress in laboratory animals, and 63 % had no knowledge of this topic.

4.5 Future plans after graduation

Students were asked about their future plans after they had finished their degree. These students were mainly planning to continue in higher education (13 students, 39.4 %), go directly into employment (10 students, 30.3 %), or take a gap year (3 students, 9.1 %). Only 5 students (15.2 %) were uncertain about what they would do after graduation, and 2 students selected “other”. All the students intending to take a gap year were planning to go back into higher education or employment on their return. Of the 14 students going into higher education they were planning to take diplomas (3 students), masters training (7 students) or PhD training (4 students); and mainly in topics related to their degree (2 students choose unrelated topics). The main reasons for going into post-graduate study were to enhance job prospects (12 students), and increase subject knowledge (17 students). Five students needed a PhD to pursue their chosen career path, and 2 students choose post-graduate study as a way of having more time to think about their career options. Only 1 student has chosen post-graduate study in toxicology, 2 in chemistry, 2 in environmental chemistry, and the remaining 7 students in other biological topics.

Those students who had chosen to go directly into employment after graduations were asked some questions about their employment prospects. From these 10 students, only 4 wanted a career in science, and only 2 of these students wanted a career in toxicology or ecotoxicology. However, 6 students would consider applying for a toxicology-related job, and all would apply for a job involving environmental science. Students seeking employment had no particular preference for the type of employer (e.g., government/public sector, international company, consultancy, university research). Students considered that their time at university had prepared them completely (10 students) or partially (19 students) for their future career, only 3 students considered this was not the case, and one respondent did not know.

5.0 Discussion of undergraduate and A-level student centred mini-survey

The survey was target to students doing one or more science A-levels, and at undergraduates doing degrees in the life sciences or chemistry topics. This will inevitably bias the results away from arts subjects, and business-related topics. The student survey was essentially an addition to the main survey of scientists. To enable a speedy response, the A-level component was conducted using mainly A-level students in Devon. The undergraduate survey component was targeted at Universities that also offered toxicology-related courses. The use of a predominantly rural population may bias the A-level responses, although it did include large towns such as Exeter, Plymouth and Bristol.

The demographics indicated that the ethnicity bias found in the survey of scientists had its roots in the student population, with the survey being completed mainly by students of a white ethnic origin. This supports the notion that other ethnic groups (all others except white) are not going into higher education as frequently, and are therefore not progressing onto scientific careers. The students had a mean age of 20 years, and there was limited evidence of mature students taking A-levels. The students were choosing the traditional A-level science topics such as biology, chemistry, maths, and physics. There was no evidence that students were avoiding the physical sciences at A-level, but equally, students were generally choosing not to do specialised A-levels within these topics (e.g., students preferring to do a biology A level rather than one of the sub-disciplines in this field).

Student awareness of the various sub-disciplines in the life sciences and physical sciences was poor, with students not being very aware of toxicology, and especially ecotoxicology, as scientific disciplines. Students were not worried about animal ethics, or the difficulty in maths and chemistry in choosing a degree in toxicology or environmental chemistry. Students simply wanted to study other topics, and avoid being too specialised at degree level (e.g., preferring a chemistry degree over a more specialist one on environmental chemistry). The main drivers for choosing degree topic were the content of the university prospectus and parental pressure. Clearly there is a need to raise awareness of toxicology topics in schools and sixth form colleges, and improve parental perception of toxicology. However, this may not change degree choice if students view toxicology topics as being too specialised for a degree.

Undergraduate students had an improved awareness of the sub-disciplines of biology and chemistry compared to A-level students, and most had at least heard of toxicology and environmental chemistry as scientific topics. Students were studying toxicology within life science degrees, but only 21 % had a toxicology module in their degree, and for these it was an option. The profile of toxicology could therefore be raised by ensuring toxicology is within core modules, and by increasing the number of degrees with some toxicology content.

Undergraduates had a good perception of the theory and practical skills coverage in their degrees, including data management/analytical skills, statistics, and report writing. This is somewhat contrary to the survey of scientists where scientists had identified some of these skills as missing or only satisfactory in the main survey. This suggests that undergraduates are either over confident about their skills, or that scientists are being pessimistic about graduate abilities. The former seems more likely given that undergraduates have not yet had the chance to prove their skills in the work place. Undergraduates had also been taught about a variety of chemicals, with no particular group of substances lacking in undergraduate training.

Final year students were mainly aiming to go further in education (post-graduate training) or to get a job. Those going into post-graduate training were remaining loyal to the scientific theme of their degree, and were willing to specialise. It therefore seems the main market for developing specialist expertise in toxicology and environmental chemistry is in post-graduate training. Of those graduates going into first employment, more than half were intending to take careers outside of science. However, this intention could be affected by job opportunity, and some of these indicated they would take a science job (including toxicology) to gain employment. It would therefore seem that there is some plasticity in career intentions of graduates, and that if opportunity is created, more students may be persuaded to start a career in toxicology or environmental chemistry.

6.0 Sample of toxicology-related degrees current available

The UCAS admissions data base was searched to establish the current availability of toxicology and related undergraduate degrees in the UK, using "toxicology" as the main search term. Courses with toxicology or related key phrases in the title are shown below (Table 22). The search was not intended to show the myriad of toxicology modules within other degree programmes, but does show a limited number of available degrees which are often co-taught with another related discipline. Degrees with "ecotoxicology" in the title are lacking.

Table 22. Toxicology and related first degrees on the UCAS system in 2008.

University (UCAS reference)	Course Title (UCAS code)	Qualification
Bournemouth University (B50)	Applied Biology (C110)	3FT Hon BSc
	Forensic and Crime Scene Science (F410)	3FT Hon BSc
The University of Bradford (B56)	Chemistry with Pharmaceutical & Forensic Science (F1B2)	3FT Hon BSc
	Chemistry with Pharmaceutical & Forensic Science (F1BF)	4SW Hon BSc
University of Wales Institute, Cardiff (C20)	Biomed Sciences (Forensic Tox) (4 yrs inc Found) (B9BF)	4FT Hon BSc
	Biomedical Sciences (Forensic Tox) (3 years) (B9B2)	3FT Hon BSc
University of Central Lancashire (C30)	Forensic Chemistry (F412)	3FT Hon BSc
University of East London (E28)	Criminology with Toxicology (M9B2)	3FT Hon BA
	Forensic Science with Toxicology (F4B2)	3FT Hon BSc
	Human Biology with Toxicology (B1B2)	3FT Hon BSc
	Immunology with Toxicology (C5B2)	3FT Hon BSc
	Pharmacology with Toxicology (B290)	3FT Hon BA
	Sports Development/Toxicology (C6B2)	3FT Hon BSc
	Toxicology (B220)	3FT/4SW Hon BSc
	Toxicology (Extended) (B221)	4FT/5SW Hon BSc
	Toxicology with Clinical Science (B2B9)	3FT Hon BSc

	Toxicology with Criminology (B2MX)	3FT Hon BSc
	Toxicology with Forensic Science (B2F4)	3FT Hon BSc
	Toxicology with Human Biology (B2BC)	3FT Hon BSc
	Toxicology with Information Technology (B2G5)	3FT Hon BSc
	Toxicology with Law (B2M1)	3FT Hon BSc
	Toxicology/Clinical Science (BB29)	3FT Hon BSc
	Toxicology/Human Biology (BB21)	3FT Hon BSc
The University of Edinburgh (E56)	Chemistry with Environmental & Sust Chemistry (F140)	4FT Hon BSc
	Chemistry with Environmental & Sust Chemistry (F144)	5FT Hon MChem
University of Glamorgan, Cardiff and Pontypridd (G14)	Forensic Chemistry (F411)	3FT/4SW Hon BSc
	Forensic Science (F125)	3FT/4SW Hon BSc
The University of Hull (H72)	Chem w. Analytical Chem & Toxicology - w Ind Exp (F186)	4FT Hon MChem
	Chemistry with Analytical Chem and Toxicology (F184)	3FT Hon BSc
	Chemistry with Analytical Chemistry & Toxicology (F187)	4FT Hon MChem
	Chemistry with Forensic Sci & Toxi(with Ind Exp) (F1BG)	4FT Hon MChem
	Chemistry with Forensic Science and Toxicology (F1B2)	3FT Hon BSc
	Chemistry with Forensic Science and Toxicology (F1BF)	4FT Hon MChem
University of Leeds (L23)	Pharmacology (B210)	3FT Hon BSc
The University of Manchester (M20)	Pharmacology (B210)	3FT Hon BSc
	Pharmacology and Physiology (BB12)	3FT Hon BSc
	Pharmacology with Industrial/Profess Experience (B211)	4SW Hon BSc
Napier University, Edinburgh (N07)	Immunology and Toxicology (BC29)	3FT/4FT Ord/Hon BSc
Nottingham Trent University (N91)	Pharmacology (B210)	3FT/4SW Hon BSc (Hons)
University of Plymouth (P60)	Toxicology and Health (BB29)	3FT Hon BSc
University of Surrey (S85)	Biochemistry (Toxicology) (3 or 4 years) (C706)	3FT Hon BSc

3FT, 3 years full time; 4FT, 4 years full time; SW, sandwich course option;

7.0 Workshop discussions

A workshop was conducted on the 11th June 2009, and invited representatives from government, industry, academia, and consultancy attended the meeting (List of Delegates, Appendix 2). The delegates were presented with an overview of the report and then formed breakout groups to critically discuss the report, and explore the main themes of the results. The feedback from the discussions are summarised below.

- Delegates made suggestions about data presentation including using the raw data (numbers) rather than percentage values where multiple replies were possible. Suggestions were also made about adding more fine detail to the data analysis. This included analysing the data on gender bias by age group, and looking at employment sector effects on the number of toxicologists or ecotoxicologists.
- Methodology issues; delegates indicated that self-selection bias was likely given that the survey was targeted at toxicologists and chemists, and this may explain the lower response from physical scientists and engineers. Response rate to the survey was also an issue because it was online (hits on the web site are recorded above). Some delegates raised issues about the precise wording of some phrases. For example, "data collection" did not necessarily distinguish between new data generation and the collection of existing data from archives.
- Reflections on personal experience compared to survey results; a number of delegates indicated that their "gut feeling" about some problems did not match the results. For example, some delegates did not experience shortages of ecotoxicologists. The explanation of this is in an employment sector analysis, with problems potentially being different in industry compared to academia or government.
- Risk assessment skills are in short supply; this was a universal view and matched the survey results. Delegates raised this as a global issue, not just a problem for the UK. Several delegates made the point that UK companies are working in global markets, and therefore may be using risk assessors outside the UK.

- There was opinion that much of the UK bench effort in regulatory toxicology was no longer being done in the UK; and sometimes not even in the European Union (e.g., hazard data collected in laboratories based in China, India etc). Therefore, we are late in addressing the bench skills shortage as this work has already left the UK. Delegates were concerned that risk assessment skills would follow the same pattern in the future, and also leave the UK. It was agreed that this must be avoided, and that it would be good if practical work could be returned to the UK as well. However, the geographical location of business is driven by cost and other market forces. If the UK community is not competitive, then work will be done elsewhere.
- Recruitment; many delegates considered that toxicology had an “image problem” and that some rebranding of the discipline was needed to attract graduates into the profession. This included scientists taking the science into schools, providing information for careers advisors who appear to have a poor or out-of-date knowledge of the disciplines, raising awareness of the training needs (e.g., in risk assessment) so that more is taught by HEIs. The media, industry, government, HEIs (everybody), had some responsibility for rebranding the image. There was a view that a shared responsibility and a multi-disciplinary approach was need to address the recruitment issue.
- Graduate training and the role of CROs; some delegates held the view that contract research laboratories were taking the risk of employing fresh graduates, unlike other sectors of the industry. The nature of CRO business is very competitive, with cost and time considerations. In this environment it is inevitable that training at the bench has a lower priority in the business needs.
- Need for bench work; in some areas of legislation there is a shift to re-using existing data in weight of evidence approaches, (Q)SARS, grouping and read-across techniques, so it maybe that bench work to generate new data is less important. However, scientific development and validation of these methodologies is incomplete meaning that there is still potential for considerable testing to be required under REACH.

Further comments were made on outsourcing work to other regions in the EU, and therefore that the bench skills are being addressed after the work has left the UK.

- Short term contracts; this remains a significant problem, mainly for the academic sector.
- Delegates preferred risk assessors to have prior bench experience, and the loss of bench work from the UK was a threat to our ability to retain good risk assessment skills in the long term. Delegates made the point that risk assessment was poorly taught, or not taught at all, in the HEI sector. Universities needed to include risk assessment modules in masters courses.
- The shortage of risk assessment skills is reflective of a much wider issue in generic skills including data analysis and interpretation skills. Delegates considered that these wider critical thinking and analysis skills were lacking. While suggestions were made that this issue was related to new graduates. There was also a suggestion that mechanisms should be in place to refresh these skills for working scientists (e.g., CPD courses).
- Suggestions on the way forward; there were many suggestions on the way forward and solutions to the problems identified in the report. These included: image rebranding, more accredited courses, more CPD/short courses or revision of existing CDP events, career awareness activity such as work placements, summer placements for undergraduates, and graduate work placements.
- Masters courses; this is likely the main training mode for HEIs in toxicology and environmental chemistry. Input from industry should be sought in the design of masters courses, with more training in critical thinking and analysis, report writing skills, and summarising skills. Risk assessment should be included as core material at masters level. The masters should not be over-specialised, but give coverage of hazard, risk, legislation, relevant biology, chemistry, and maths. For example, a masters in “ecotoxicology” may be too specialised at masters level, and an expanded theme to include chemistry and risk assessment would be

better. In short, make masters training more interdisciplinary. Research councils should finance HEI initiatives, but industry should also be involved.

- Market forces and globalisation; the findings of the report and recommendations should reflect the global nature of business.

8.0 Interviews

A number of telephone and face-to-face interviews were conducted in order to refine some of the general responses obtained from the survey. A summary of these discussions is given below.

- The influence of animal rights issues was more equivocal than that suggested above. One interviewee found that an increasing number of students were refusing to carry out practical work that used animals on the grounds that it is ethically unacceptable. Another interviewee thought that parental influence was also a key factor in a student's attitude to animal experimentation and that informed debate covering all issues, both for and against, often resulted in students recognising the need for such experimentation to take place. Projects carried out in schools are often based on emotive material gleaned from the internet without sufficient examination of the science. Industry is finding it difficult to recruit staff in the area of *in vivo* pharmacology due to low and declining interest. This was thought to be caused by a general lack of clarity around the future of *in vivo* testing as a career path within industry and animal rights activists acting as a deterrent to pursuing a career in this field.
- In addition to those listed above, the following skills were thought to be missing in undergraduate training for toxicologists: understanding risks in context, (i.e., real world scenarios), understanding the limitations of epidemiology, biochemistry, chemistry, anatomy and physiology, basic assay skills, cell culture, design of toxicological studies.
- In addition to those listed above, the following skills were thought to be missing in masters training for toxicologists: molecular toxicology, *in vitro* toxicology, understanding whole animal toxicology, cell culture,

gene array work, translational safety science (the ability to critically evaluate the safety of chemicals by linking *in vitro* and animal data with human data).

- Toxicology was viewed as an applied science and not necessarily something that could/should be taught at undergraduate level. A good understanding of the three basic scientific disciplines (biology, chemistry and physics) was considered more useful at undergraduate level, especially during the first two years, with perhaps some specialism in the final year. The need for cross-discipline skill sets came up repeatedly. Information on career opportunities in toxicology/ecotoxicology should be targeted at second year undergraduates.
- Targeted CPD courses and professional accreditations were seen as potentially more practical for meeting the skills gap, rather than trying to “specialise” undergraduate programmes. In addition, if the requirement for CPD becomes greater more time will be allowed for training by companies, especially if the result is a better skilled workforce.
- It was felt by some interviewees that industry already provides a large amount of money to universities and that they are unlikely to want to sponsor undergraduates as this would be regarded as too risky. Students are also unlikely to want to tie themselves to an employer at such an early stage before they know how well they will perform in their chosen subjects.
- Cross fertilization of ideas between toxicologist and ecotoxicologists; a number of chemicals of concern to human health were first identified/received publicity as environmental contaminants, e.g. estrogens, phalates, bisphenol A, flame retardants.
- Toxicology/ecotoxicology lacks an attractive profile. Many students entering masters programmes in toxicology have studied forensic science at undergraduate level. PhD students in ecotoxicology are attracted by “a desire to protect wildlife”.
- Skilled use of analytical instruments was viewed as something that can only be achieved through continual use. Sample preparation requires

practice and time, neither of which is available in most course modules. The machinery is often very expensive and institutions are reluctant to let inexperienced students use such expensive instruments.

- Secondments. Several interviewees suggested that for individuals working on desk-based projects, which included reviewing laboratory studies, could benefit from secondments into a laboratory-based job. It was recognised that there may be issues with data confidentiality and Home Office licensing. Likewise, laboratory based personnel could benefit from secondment into a regulatory/policy orientated organisation.
- Communication links between industry and higher education providers need formalising so that HEIs can tailor their provision.

9.0 Current initiatives

A number of the interviewees and workshop delegates reported current initiatives that they were personally involved in, and are relevant to the skills and capacity issue. These are summarised below.

9.1 European Toxicology Risk Assessment Training Programme: TRISK

Risk assessment skills were identified as key skills gap in this survey. The need for trained risk assessors with a strong background in toxicology and familiarity with the current EU legislative framework is something that has been identified by the EU Commission. A shortage was identified not only in respect to the long-term sustainability of risk assessment advice to EU and national bodies but also to the private sector. The Health and Consumers Directorate General (DG Sanco) commissioned a preliminary study in 2007 to provide a comprehensive inventory of training schemes capable of training scientists to serve on the non-food Risk Assessment committees. The demand for new recruits to serve on these committees increased following a Commission decision limiting the time period over which any individual can remain eligible to serve on any of its scientific committees. The study indicated that training courses specifically covering risk assessment were not available, and an informal brainstorming meeting[3] on risk assessment capacity in Europe organised by DG SANCO following receipt of the study arrived at similar conclusions to the current survey. The conclusion was that actions were needed on three interlinked areas:

- University training and academic research in (eco)toxicology
- Post-graduate training in risk assessment sciences
- Certification of trained Risk Assessors.

The following initiative has resulted under the acronym of TRISK. The European Toxicology Risk Assessment Training Programme is organised by TRISK, a project that is funded by the EU, under the framework of the Second Programme of Community Action in the field of Heath (2008-2013). Five European universities and one research consortium are partners in this project, with the University of Surrey, representing the UK.

The objective of the training programme is to provide a comprehensive training in toxicological risk assessment that serves as a model for future European training in risk assessment for accredited European risk assessors. Further information is available at www.trisk-project.eu (available from July 2009). The project is still in its infancy and interested parties are encouraged to visit the website.

9.2 Innovative Medicines Initiative (IMI)

Current drug safety education and training in Europe lacks an integrative and translational approach, a shortfall identified by The European Federation for Pharmaceutical Sciences (EUFEPS). The IMI ('Strategic Research Agenda'), the US Food and Drug Administration (FDA) and the European Medicines Agency (EMEA) have also characterised this fact as a crucial gap in the education and training of scientists evaluating the safety of drug candidates and new medicines. The IMI is a partnership between the European Community and the European Federation of Pharmaceutical Industries and Associations (EFPIA), the aim of which is to support the faster discovery and

[3] Informal Brainstorming Meeting on Risk Assessment Capacity in Europe – Supply and training of Risk Assessors organized by DG SANCO, November 10, 2007 and March 10, 2008. Reported in Risk Assessment Advanced Training Program (RAAP) Guidelines; available from http://ec.europa.eu/health/ph_risk/documents/cons_guidelines_en.pdf

development of better medicines. EFPIA represents 31 national pharmaceutical industry associations and 44 leading pharmaceutical companies operating in Europe. Under the auspices of the IMI, a new and unique pan-European education and training network seeks to solve this shortfall by developing and establishing a comprehensive modular Education and Training Programme in Safety Sciences for Medicines (*Safe SciMET*) This programme is designed to meet the needs of pharmaceutical industry, regulatory authorities and academia. The network of 18 partners consisting of top institutes for drug safety education and research proposes a new type, high quality and sustainable programme for education and training in Safety Sciences for Medicines (*S2M*). The tailor-made training modules will encompass the safety, ethical, regulatory and societal aspects in all phases of drug development, with emphasis on integrative, translational and 3Rs aspects of drug safety assessment. Individual safety professionals who wish to address specific knowledge gaps will be able to follow single courses. The modular set up also provides opportunities for students to follow single modules as well dedicated subsets of modules, to be accredited for CPD. Scientists successfully completing the full programme, including an integrative MSc-thesis will be awarded with an accredited Master of Advanced Safety Sciences of Medicines (*MAS2M*). Further information can be found at http://www.imi-europe.org

9.3 Universities of Reading and Surrey Biopharma Skills project

The University of Reading has been awarded £689,185 from HEFCE's Economic Challenge Investment Fund (ECIF) for a collaborative project with the University of Surrey to address the immediate and long-term skills and knowledge needs of the biopharma industry in the South East. The South East England Development Agency (SEEDA) will contribute £344,593 match funding. The ECIF was set up to help universities respond rapidly to meet the immediate needs of individuals and businesses during the recession.

The Reading-Surrey project will support the development of targeted opportunities for employees, the recently unemployed, and graduates facing a depleted job market, particularly in areas the biopharma industry has identified as high priority. The ECIF funds will help remove the financial and practical barriers that prevent a wider range of individuals from accessing the universities' expertise, particularly in the current financial climate. The universities are keen to ensure that regional SMEs have every opportunity to benefit from the enhanced and subsidised provision.

The scheme grew out of an investigation at the University of Reading into how universities in the South East might work in collaborative and complementary ways, both with each other and with industry; to better serve the skills needs of the regional biopharma industry. It therefore addresses not only the biopharma industry's short-term needs, but also its long-term sustainability in the region. The planned activities will help enhance the current and potential workforce, in order to sustain an industry of prime importance to the nation's and region's economic wellbeing. The project will be the first step in setting up a Centre for Skills and Knowledge Exchange for the Biopharma Industry in the South East.

The project will last until September 2010, and will comprise three main elements:

- Employment of four Industry Liaison and Internship Fellows to: develop relationships between businesses and the universities; identify specific and urgent training needs; develop and facilitate the development and delivery of specialist education and training in HEIs and industrial bases; mentor graduate interns (relieving pressure on host SMEs); and work with university careers advisers to develop specialist knowledge. Fellows will have a strong biopharma industry background. They will bring broad sector knowledge, specialist expertise, excellent communication skills, and an interest in industry-related teaching and learning in industrial and academic contexts.
- Full funding of 18 graduate internships combining industry-based work with higher-level education and skills development in the universities, to develop interns' own expertise in areas of key interest to the industry, and to contribute to the work of host companies drawn from across the sector. Interns will be recent graduates recruited on a competitive basis according to aptitude for and interest in careers in biopharma, particularly in areas of skills shortage (e.g., *in vivo* work).

- Provision of free CPD courses for the graduate interns on the scheme at the Host Universities

9.4 Medical Research Council (MRC) Integrative-Toxicology Training Partnership (ITTP)

The MRC ITTP initiative is aimed at improving and securing capacity in the toxicological sciences by providing 4 year PhD studentships for training in the toxicological sciences so that students develop a broad appreciation of toxicological issues and language. Collaborative partnerships in universities and with other relevant organisations, including industry and Government agencies are encouraged. The ITTP also provides Career Development Fellowships (CDFs) which are aimed at postdoctoral fellows (3 – 8 years after a PhD or MD degree) who wish to conduct research within the broad framework of toxicology. (For further information http://www.le.ac.uk/mrctox/MRCTox/ittp.htm

9.5 Natural Environment Research Council (NERC)

The NERC is currently undertaking a review of “Skills Needs and Postgraduate Training Priorities in Environmental Sciences”, in conjunction with the Environment Research Funders’ Forum (ERFF). This exercise is due to be completed in 2010. The scope will include both toxicology and ecotoxicology. The objectives of the review includes: developing a list of environmental science skills which require postgraduate training, identifying the future UK skills needs in environmental sciences sector, identifying gaps in evidence and make recommendations for change, including training that should be stopped and the need for increases in particular areas. The initial work on the “Skills Need” review has highlighted the difficulty people have in quantifying the subject area as evidenced by phrases such as “apparent shortfall” and “perceived reduction in”. This highlights the need for better data and information about skills and the destination of scientists at a more detailed level than is currently provided by HESA data (pers, comm. NERC). NERC also supports a number of masters courses that include ecotoxicology, and for example, the molecular mechanistic toxicology/toxicology course provided by

University of Birmingham School of Biosciences (http://www.nerc.ac.uk/funding/available/postgrad/awards/masters/2009.asp.).

10.0 Conclusions and recommendations

The main conclusions and recommendations are summarised below, in addition to the comments in the discussion sections above.

10.1 Equality in the professions

The main conclusion of the survey on equality is that both gender and race inequalities exist. The survey of scientists showed a male: female balance of roughly 2:1 in the workforce that was generally contrary to that in the student population. This suggests that female graduates are less likely to take employment in toxicology and related disciplines, but once in the profession, equal opportunity seems probable for females (e.g., similar years of service and age distribution to males). Non-white ethnic groups are poorly represented in the disciplines, and the main cause of this is at the level of higher education. The recommendation is to address the issues of graduate recruitment of females into the workplace by a more detailed analysis of the attitudes of female graduates compared to males, and taking appropriate remedial action such as targeting careers information at female undergraduates in stage 2 (year 2) of their degrees. The ethnic group bias is more difficult to address, as this is a science-wide issue, not just for toxicology. Nonetheless, we need to encourage more Asian, Black and Chinese ethic groups into our science. This needs to done at school, and we recommend outreach activities where working scientists have some direct contact with these specific groups, and school children generally. This needs to be done at a critical point (e.g., just before students select GCSEs and A-levels) for maximum effect.

10.2 Professional background and skills of our current scientists

The main conclusions are that our scientists are a well qualified and very loyal workforce, with an overall good coverage of knowledge on different types of chemical substances, including new substances like nanomaterials. However, there is an employment sector bias with more toxicologists in industry than other areas, and the ecotoxicologists are mainly in academia. Only a fraction of the UK workforce is conducting practical work at the bench, and most of this is in academia, with the perceived departure of regulatory toxicity testing to laboratories outside the UK. The shortage of toxicologists and chemists in industry is a significant threat to our immediate and medium term predicted work requirements under REACH (and other legislation) if the UK alone is considered. However, companies may have the option to move work to laboratories outside the UK. The skill of the workforce is only one factor in this problem of UK competitiveness.

Our recommendations include attracting more ecotoxicologists into sectors outside of academia. Activity to address this should be targeted at post-graduate ecotoxicologists, and should include training in risk assessment and regulatory ecotoxicology so that these post-graduates understand the career paths outside of academia. In addition to recommending the recruitment of more toxicologists and chemists in all sectors to combat increasing workloads and long hours, there is a particular need to retain the toxicology training capacity in HEIs by recruiting research-active academics in toxicology with a specific focus on post-graduate training. The decline in the academic base is a significant threat to the long term supply of toxicologists. Similarly, the shortage of toxicologists in industry is one of a number of threats that make the UK a less attractive commercial environment for companies conducting regulatory toxicology. A broader package of incentives will be needed to retain the industry in the UK.

10.3 The skills gap

The data supports the conclusion that priority skills gaps include risk assessment skills, practical knowledge of regulation and policy, statistics, specific specialist bench skills, generic report writing skills, and practical aspects relating to *in vivo* experience with animals.

Our recommendations include post-graduate training in practical risk assessment skills and on regulations/legislation. These should be core topics in masters-level training, not options, and the design of masters programmes should have more involvement from scientists working in industry and government. Skills in statistics, report writing and other generic skills are being taught in academia, but these are being lost on entering employment. CPD training in these areas, and other forms of refresher training should be made available to scientists in all sectors, but especially industry. Specialist bench skills can partly be addressed by increasing the practical work in final year degrees and in masters training, but this only introduces early-career scientists to the techniques. True proficiency is obtained with continuous use and experience of a technique or instrument, industry must take steps in its business planning to ensure that this training is maintained in their current employees; and that procedures are in place to transfer these skills to new staff, and with practical CPD training at the bench to keep up with changes in the technology. Animal welfare and practical experience of working with animals can be addressed by including this in undergraduate teaching, and by making this training of a more mandatory nature at post-graduate level. Action on the latter needs to be taken quickly, as the number of academics with a high level of practical expertise of *in vivo* have declined.

10.4 Predicted work loads

We conclude that the need for hazard and risk assessment of chemical substances will increase with the current and new legislations, including REACH. The inevitable variety of nanomaterials will add to this burden. The analysis of the working environment indicates that organisations anticipate they will use sub-contracting and other methods to meet increased workloads, but staff in all sectors already perceive long working hours. We therefore recommend a recruitment drive and capacity building in all aspects of employment, and especially in those identified in the skills gaps above. There are not enough staff to do all the work predicted, and this must be linked to retaining industry and skills in the UK. Many of the UKs important industries are global companies making it easier for them to source missing skills from abroad, or arrange for work to be carried out in other countries. This has already happened in the pharmaceuticals industry (ABPI 2008), where skills supply is a core element of effectiveness, and therefore partly influences the ability of companies to attract investment.

10.5 Recruitment

We conclude that the skills shortage is partly caused by an inability to recruit new staff, and a lack of suitable applicants with the necessary skills was an issue for all sectors of employment. Once in the workplace, new staff need to be properly supported with further training and mentoring. Our recommendations include modifying masters-level training, in consultation with industry, so that the skills set of these graduates more closely matches the expectation of employers (e.g., modules on risk assessment and regulatory toxicology, more training with live animals and study of anatomy/whole animal physiology, more relevant training in statistics, more practical experience in toxicology). More time should be devoted to practical training of undergraduates, and with stage 3 modules in toxicological sciences to raise skills and awareness of this career path in life science degrees. Training and maintaining skill levels in the workplace is important, and there are many modes of delivery of such training, but short courses/CPD events were popular with respondents, as well as creating opportunity for staff to go back to higher education for a short time (e.g., to do masters level training).

10.6 Responsibility for training

Practical training at the bench is currently conducted by a relatively small sub-set of scientists, and most of these are in academia, with some in industry. The scientific community has a shared responsibility for training, and an ethos and working environment needs to be established where experienced staff have the time, resources, and inclination to train others. This task should not be left solely to the academic sector, and we recommend that training events should include important contributions from staff working in industry, government and consultancy. It would be appropriate to establish a more widely available accreditation scheme (wider than the scope/purpose of the current Register of Toxicologists) so that such training events are encouraged and recognised. For example, by involving the relevant learned societies in accreditation for toxicology, ecotoxicology, and environmental chemistry respectively.

10.7 Student perception, undergraduate training, and the image of toxicology

Students are generally not choosing specialist degrees in the discipline, and the consensus view is that undergraduate training should remain broad, and that most of the specialist training in the toxicological sciences should occur at post-graduate level. Nonetheless, generic skills and practical skill levels of graduates remain a concern for respondents, and steps should be taken to ensure more time is spend on these skills during degrees, to increase the likelihood of students retaining these skills after graduation. The balance of practical and theory in degrees should be addressed. Awareness of toxicology needs to be raised at undergraduate level to ensure a supply of students interested in post-graduate training. This can be done by including toxicology-related modules in the relevant life science, biomedical science, and chemistry degrees. More involvement of industry, government and consultancy can be achieved through summer placement schemes, year placements in industry, and graduate placement schemes. Career awareness needs to be raised by scientists making visits to sixth form colleges, and by engaging undergraduates in stage 2 of their degrees before they make their final year choices. Careers advisors have not been effective, and we recommend training workshops to brief careers advisors on current career paths and activities in toxicology and chemistry. The career path also has an "image problem", and graduates are less likely to embark on careers in the toxicological sciences. We recommend increasing the level of public engagement of our science, and in particular engaging the attitudes of parents with students in higher education, as well as the students themselves. More emphasis needs to be placed on the beneficial effects to society (e.g., cleaner environment, increased food safety, better/safer medicines etc.) as well as the exciting and dynamic career prospects in the professions.

10.8 Retaining and training post-doctoral scientists

Post-doctoral scientists are a vital resource of current and experienced bench skills. These post-doctoral scientists will also be the senior scientists/scientific leaders of the future, and this group should be protected. Most of the early post-doctoral training is done in academia, and we recommend that academics and staff from industry are released from other duties to engage in post-doctoral training. Short term contracts and continuity remains a specific problem in the academic sector, and targeted post-doctoral fellowships will help to retain experience in the profession.

10.9 Communication and implementation of the recommendations

The workshop discussion, and the apparent contradiction between student perception of their skills, and the views of respondents in different sectors highlighted the multi-faceted nature of the skills problem. Effective communication and cohesive effort involving all sectors of employment is critical to delivering the above recommendations. One potential way forward is to create a body/working group with overall responsibility for co-ordinating the implementation. Implementation issues have already been identified following recommendations on biomedical training (ABPI, 2008), and effective implementation will be even more important here given the very multi-disciplinary nature of training in toxicology and related areas. The flow of knowledge between all sectors, not just from universities to industry, would currently appear to be dependent on personal contacts rather than structured communication pathways. A more permanent forum for monitoring the skills issues is needed.

A number of training initiatives are already underway (outlined above), and it may be possible to coordinate implementation of the recommendations in this report with such activities. Similarly, existing forums, such as the Toxicology and Safety Science Forum which brings together a variety of stakeholders in toxicology (see Appendix 3) could be used to discuss training initiatives between academia, industry, government and funding agencies. This forum may be a particularly good vehicle to bring industry, and especially the perspectives of CROs into toxicology training. A similar forum for ecotoxicology, and environmental chemistry, also needs to be established. In the UK, an ideal vehicle would be the Society of Environmental Toxicology and Chemistry (SETAC-UK branch; http://www.setac-uk.org.uk/index.html) which already has representation from government, industry, academia, and consultancy; and is one branch in a global society.

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APPENDIX 1. Listings of cohorts who were sent the toxicologist's questionnaire.

1. *UK Ecotoxicologists and regulators*- UK resident members of the Society of Environmental Toxicology & Chemistry UK Branch (SETAC-UK), and the current council, were emailed a link to the survey. This included SETAC Europe members who were UK scientists. These members come from government, industry and academia.
2. *Toxicologists*-similarly, an email invitation to the survey link was sent to other relevant societies (e.g., British Toxicology Society, In Vitro Toxicology Society, United Kingdom Environmental Mutagen Society). Several members of team are in these societies.
3. *Animal Biologists and welfare experts*- The Society for Experimental Biology, one of the largest societies with a detailed knowledge and history of a diverse range of skills in animal biology.
4. *Environmental Chemists*- via members of the Royal Society of Chemistry, Society for the Chemistry Industry.
5. *Nanomaterial experts*- A data base of over 200 scientists who attended the recent meeting series on "Environmental Effects of Nanoparticles and Nanomaterials".
6. *Clinicians and pharmaceutical industry*-the survey invitation was sent to the Peninsula Medical School at Plymouth/Exeter Universities, and also by personal contacts Prof. Handy has with the BARQA board (British Association for Research Quality Assurance) which is the umbrella organisation involved in setting and debating quality standards for clinical safety trials of pharmaceuticals. Also to specific colleagues in ABPI.
7. *Veterinary experts*-questionnaires were sent to veterinary surgeons at the Home Office, who also circulated to members of the Veterinary Laboratory Agency, and to colleagues in the Royal College of Veterinary Surgeons.
8. *Regulators & policy makers*-clearly this will involve government departments, policy review bodies, and NGOs who hire these professionals including Defra, Food Standards Agency, Royal Commission, Environment Agency, Scottish Environmental Protection Agency, Natural England, Health & Safety Executive, etc. A selection of colleagues were approached from these organisations.
9. *Research Councils*-NERC, BBSRC, NC3Rs and MRC would likely cover most areas where toxicologists gain funding for fundamental research. The link was emailed to relevant co-ordinators, e.g., the environmental nanoscience initiative at
10. *Companies performing regulatory toxicology*: The main CROs in the UK. For example, staff from the learned societies above who are employed in this sector.
11. *Health and Safety experts*-HSE lab Taunton, Institute for Occupational Medicine, Edinburgh.
12. *Higher Education Establishments*; Many of these were captured in the above grouping, but we also emailed biology and chemistry departments at some universities conducting toxicology or related degrees.

13. *Post*-graduate students; these were included as sub groups in the learned society mailing list, a significant proportion of membership is PhD students or early fellows.
14. *Undergraduate students*; students at Plymouth University, and colleagues at other key universities were asked to draw the link to the attention of their students (e.g. Napier, Kings, Reading). All sixth forms in Devon were also emailed the survey link to the student-centred survey.
15. *Animal Welfare organisations*; These included NCRs, and members of the RSPCA (who also happened to be SEB members).
16. *Consultancy*-a variety of independent consultants were invited to complete the survey.

APPENDIX 2. Delegates of the workshop held on 11th June 2009

Name	Organisation
Dr Nic Bury	Centre for Environmental Assessment, Management & Policy, Kings College, London
Dr Peter Campbell	Senior Environmental Specialist: Head of Research Collaborations, Syngenta Limited
Mr John Chadwick	Health & Safety Executive
Dr Helen Compton	Chemicals and Nanotechnology Division, DEFRA
Dr Robin Fielder	General Toxicology Unit, Chemical Hazards & Poisons Division, Health Protection Agency
Dr Rosemary Gibson	In Vitro Toxicology Team Leader, Health Improvement Group, Health and Safety Laboratory (HSL)
Dr David Gott	Chemicals Safety & Toxicology Division, Food Standards Agency
Mr Paul Hamey	Health & Safety Executive (HSE)
Prof. Richard Handy	University of Plymouth
Dr Paul Harrison	PTCH Consultancy Limited
Dr Awadhesh Jha	University of Plymouth
Mr Dean Leverett	Senior Scientist (ecotoxicology) Environment Agency
Dr Jo Lloyd	Director, REACHReady
Dr Dawn Maycock	Director, Environmental Toxicology & Risk Assessment, wca environment limited
Mr Tom Perriment	Department for Innovation, Universities, and Skills (DIUS)
Ms Jenny Poulter	Environmental Safety Assessor, Veterinary Medicines Directorate (VMD)
Dr Mike Roberts	Chemicals and Nanotechnology Division, DEFRA
Mr Dave Sheahan	Senior Chemical Risk Assessor, Centre of Environment Fisheries and Science (CEFAS)
Dr Andy Smith	MRC Toxicology Unit, Leicester University
Mr Kirit Wadia	Principal Ecotoxicologist, Alcontrol Laboratories
Dr Paul Wilkes	Head of Regulatory Affairs, The Body Shop International Plc

The following people provided useful comments on the first draft of the report:

Dr David Basketter, DBMEB Consultancy Limited

Dr Caroline Culshaw, NERC

Dr Shirley Price, University of Surrey

Professor John Sumpter, Brunel University

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BBSRC
Cranfield University
Department of Pharmacology, University of Oxford
Food Standards Agency
GlaxoSmithKline
Health & Safety Executive
Huntingdon Life Sciences
Imperial College, London
Kings College, London
Medical Research Council
MHRA
Newcastle University
Pfizer
Sanofi-aventis
The University of Bradford
The University of Dundee
Unilever
University of Aberdeen
University of Bath
University of Birmingham
University of Leicester
University of Liverpool
University of Manchester
University of Surrey

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